AD/A-001 087

RADC SOI TEST FACILITY TECHNICAL ASSISTANCE PROGRAM

T. Grish, et al

Riverside Research Institute

Prepared for:

Rome Air Development Center
Defense Advanced Research Projects Agency

31 July 1974

AD A001087

RADC-TR-74-251
Final Technical Report
31 July 1974

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TECHNICAL ASSISTANCE PROGRAM

Riverside Research Institute

Sponsored By
Defense Advanced Research Projects Agency
ARPA Order No. 2080

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

This report describes research performed at Riverside Research Institute and was prepared by E. Weitzman with contributions from members of the research staff.

The work described herein was supported by the Defense Advanced Research Projects Agency of the Department of Defense and monitored by Rome Air Development Center of the Air Force Systems Command, USAF, under Contract No. F30602-73-C-0097.

This report has been reviewed by the RADC Information Office (OI), and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved.

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RADC Project Engineer

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RADC-TR-74-251	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A-001 087
4. TITLE (and Subtitle) RADC SOI Test Facility Technical Assistance Program		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report 30 Jan 73 - 30 Jul 74
		6. PERFORMING ORG. REPORT NUMBER F-1/280-4-00
7. AUTHOR(s) Mr. T. Grish and Mr. E. Weitzman		8. CONTRACT OR GRANT NUMBER(s) F30602-73-C-0097
9. PERFORMING ORGANIZATION NAME AND ADDRESS Riverside Research Institute 80 West End Avenue New York New York 10023		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62301D 20800002
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington VA 22209		12. REPORT DATE 31 July 1974
		13. NUMBER OF PAGES 103
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Rome Air Development Center (OCTM) ATTN: Richard A. Ackley Griffiss AFB NY 13441 Phone 315 330-4026		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release. Distribution unlimited.

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Wideband Radar Sensors
Computing capability for High Resolution Radar Control & Guidance High Resolution Techniques

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This final progress report summarizes the technical status of tasks sponsored by the Strategic Technology Office of the Defense Advanced Research Projects Agency and carried out for the Rome Air Development Center (RADC) of the Air Force Systems Command, USAF, under Contract No. F30602-73-C-0097, during the period 1 Feb 73 to 31 Jul 74. During this period Riverside Research Institute's efforts were concentrated primarily on (1) providing technical guidance and assistance to RADC and its O&M Contractor, RCA, in carrying out measurements and

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upgrading of the transmitter and signal processing subsystems, (2) carrying out a study of requirements for, and recommendation of, candidate on-site computers, (3) acquisition of a third generation computer for the Floyd Site Wideband Radar, and (4) preliminary design for integrating the computer into the radar.

RADC SOI TEST FACILITY
TECHNICAL ASSISTANCE PROGRAM

Mr. T. Grish
Mr. E. Weitzman

Contractor: Riverside Research Institute
Contract Number: F30602-73-C-0097
Effective Date of Contract: 30 January 1973
Contract Expiration Date: 31 July 1974
Amount of Contract: $224,192.00
Program Code Number: 2E20

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Approved for public release;
distribution unlimited.

This research was supported by the Defense Advanced Research Projects Agency of the Department of Defense and was monitored by Richard Ackley, RADC (OCTM), GAFB, NY 13441 under Contract F30602-73-C-0097, Job Order No. 20800002.

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This Final Progress Report summarizes the technical status of tasks sponsored by the Strategic Technology Office of the Defense Advanced Research Projects Agency and carried out for the Rome Air Development Center (RADC) of the Air Force Systems Command, USAF, under Contract No. F30602-73-C-0097, during the period 1 February 1973 to 31 July 1974. During this period Riverside Research Institute's efforts were concentrated primarily on (1) providing technical guidance and assistance to RADC and its O&M Contractor, RCA, in carrying out measurements and upgrading of the transmitter and signal processing subsystems, (2) carrying out a study of requirements for, and recommendation of, candidate on-site computers, (3) acquisition of a third generation computer for the Floyd Site Wideband Radar, and (4) preliminary design for integrating the computer into the radar.

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I. INTRODUCTION AND SUMMARY

This Final Report summarizes the technical status of tasks sponsored by the Strategic Technology Office of the Defense Advanced Research Projects Agency and carried out for the Rome Air Development Center (RADC) of the Air Force Systems Command, USAF, under Contract No. F30602-73-C-0097, during the period 1 February 1973 to 31 July 1974. Following is a brief description of this program.

ARPA became interested in participating with the Air Force Rome Air Development Center (RADC) in a joint program of research in Space Object Identification (SOI). Initial work in object identification was begun at RADC more than seven years ago when personnel of the Advanced Technique Branch proposed the development of a high resolution S-Band radar for this purpose. This radar was ultimately constructed at the Floyd Test Annex, located about ten miles from Griffiss Air Force Base, Rome, New York. In connection with the wideband work for SOI, RADC also supported efforts at Syracuse University Research Corporation (SURC) for development of signal processing techniques to accomplish radar imaging of objects in earth orbit using coherent synthetic aperture type processing of echoes from very wide bandwidth microwave radar to achieve two-dimensional imaging.

For a variety of reasons, the microwave radar at the Floyd Test Annex had not collected high quality, high resolution data, although it had successfully tracked earth satellites. However, the soundness of the wideband techniques being supplied in the radar and data processing had been demonstrated using data collected by the MIT Lincoln Laboratory ALCOR radar. These results

very strikingly demonstrated the power of this technique to obtain useful information about the size and shape of orbiting objects.

At the request of ARPA, RRI personnel undertook an examination of the microwave and optical radars at the Floyd Test Annex to determine their general condition and whether any critical deficiencies were present. The results of this investigation, which was carried out in early April, 1972, were presented in Ref. 1.*

Subsequently, ARPA tasked RRI to provide engineering services to assist in the planning, testing, upgrading, and operation of the RADC SOI Test Facility. These services were required to ensure the collection of high-quality radar data.

During the 18-month period covered by this report RRI's efforts were concentrated primarily in (1) providing technical guidance and assistance to RADC and its O&M Contractor RCA in carrying out measurements and upgrading of the transmitter and signal processing subsystems, (2) carrying out a study of the requirements for, and recommendation of, candidate on-site computers, (3) acquisition of a third generation computer for the Floyd Site Wideband Radar, and (4) preliminary design for integrating the computer into the radar.

Decisions to replace several radar components and subsystems were made by RADC prior to the start of RRI's involvment. Although in the beginning, only a minimal effort was required of RRI in connection with these equipment procurements, RRI became more involved as these subsystems and components arrived at the Facility for integration and check-out. There were many delays in obtaining the equipment as will be discussed in the sections to follow. New pulse-compression equipment, from Creative Electronics, Inc., was installed in November, 1973.

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* For numbered references, see Section V.

The sidelobe levels were 10 dB better than previously used equipment. The replacement of the linear wideband sweep generator, originally awarded to Watkins-Johnson Company, became an in-house project when Watkins-Johnson was released from their contractual obligations, having not fully comprehended the special requirements for building such a linear sweep generator. Due to this set-back, the sweeper development was limited to passive compensation. Integration of the sweeper with the transmit/receive channels was successfully completed.

Up/down converters were built by Airborne Instrument Laboratories and integrated successfully into the signal processing hardware in April, 1974. Transversal equalizers were built by Hazeltine and were accepted at the Floyd Site towards the end of November, 1973. New RF and IF amplifiers were obtained from Miteq, Inc. and Sage Laboratories, Inc. respectively.

Substantial improvements were achieved in the transmitter. It was made to operate with a 40 μsec pulse rather than a 20 μsec pulse. Its amplitude and phase characteristics were improved to the point where the open loop phase correction and transversal equalizers were capable of reducing remaining nonlinearities to acceptable levels. Final amplifier output was made to be close to the value specified by Varian, the manufacturer.

As a result of its computer selection study, RRI recommended two candidate computers for installation at the Floyd Site. Selection depended heavily on the intended future status of the Floyd wideband radar and its level of mission activity. For an experimental or a light operational role, a Digital Equipment Corporation PDP-11/45 computer was recommended. For heavy "operational" status and for testing of real-time imaging techniques, a Xerox Data System Sigma-5 machine was recommended.

The report on this study, "Computer Upgrading For The RADC Wide-Band Pulse Compression Radar," is in the Appendix of this Final Report.

In the latter part of November 1973, RRI was directed by the White Sands Missile Range to terminate activities at the AMRAD facility. RRI had responsibility for scientific direction of the AMRAD program for several years, and by virtue of its involvement in the program, RRI was able to arrange the transfer of the Xerox Data System Sigma-5 computer from the AMRAD facility to the Floyd Site. Other AMRAD equipment useful at the Floyd Site was transferred as well. The Sigma-5 was successfully installed and became operative in April 1974.

A preliminary design of a Radar Control and Data Processing System (RCDPS) to be interfaced with the Floyd Site WPCR was completed. The RCDPS utilized the XDS Sigma-5 computer and other special purpose equipment obtained by RADC from the AMRAD facility. This system was designed to provide the WPCR with the extended capabilities of (1) pre-experiment ephemeris sorting and pointing data table generation; (2) automatic radar calibration and checkout; (3) real-time radar control, data display, and signature data acquisition and recording; and (4) post-mission data reduction and diagnostics. The system offered significant enhancement of the WPCR capabilities in the SOI program, and provided increased flexibility of operation of the radar as well as rapid turn around on mission data processing (on-site).

Shortly after the Sigma-5 became operative, word was received that the Wideband Pulse Compression Radar would be shut down on 1 July 1974 due to lack of support and need in the Air Force. An effort was made to complete installation of the newly acquired equipment and demonstrate operation of the wideband system at least once. However, some timing and range tracker

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problems occurred, making it obvious that the demonstration would not be possible before site closing. For that reason, radar operation work ceased and termination procedures began.

II. SUBSYSTEMS MEASUREMENTS AND STATUS

Decisions to replace several radar components and subsystems were made by RADC prior to the start of RRI's involvment. Although in the beginning only a minimal effort was required of RRI in connection with these equipment procurements, RRI became more involved as these subsystems and components arrived at the Facility for system integration and checkout. For purposes of orientation as to where the various components and subsystems were functionally located in the radar, the block diagram of Fig. 1 is provided.

A. RECEIVER AND SIGNAL PROCESSING EQUIPMENT

1. Pulse-Compression Equipment

New pulse-compression equipment was ordered by RADC from Creative Electronic, Inc. The original pulse-compression lines allowed operation with only a 20-μsec pulse whereas 40-μsec operation was desired. The original delivery data promised by the vendor was May 1, 1973. However, early in the manufacture of the surface-wave delay lines a design error was uncovered. The dispersion grating was generating almost twice the specified frequency due to an incorrectly designed grid mask. A revised delivery date of August 1, 1973 was therefore announced by the vendor. Apparently the manufacturer misunderstood the specification for the output signal frequency, and thus a redesign of certain mixers and filters was required.

Early in November 1973, acceptance tests indicated that the required dynamic range of 50 dB was not being met. In addition, time sidelobe levels were excessively high due to a misadjustment in the weighting filter. Subsequent tests

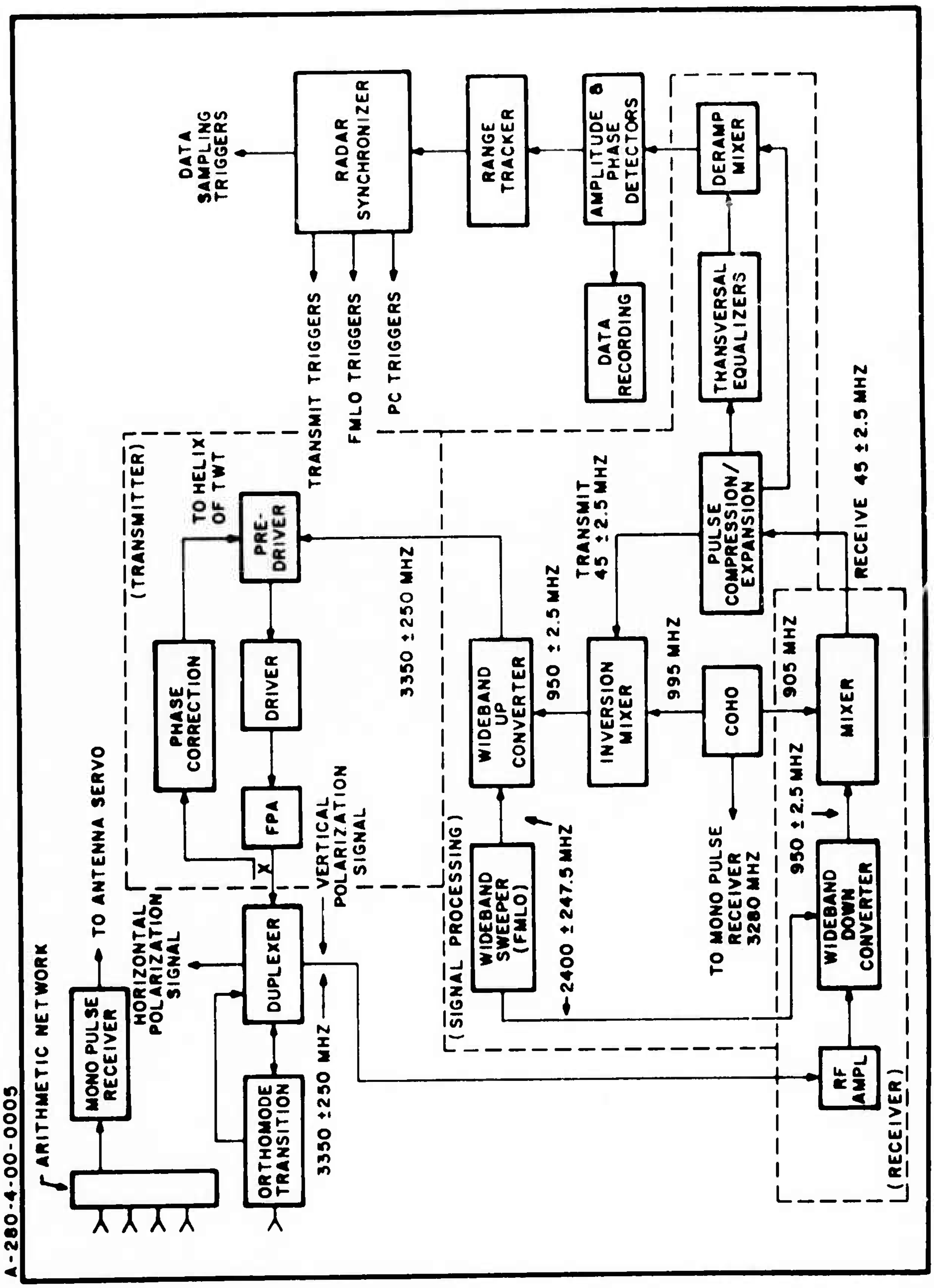


FIG. 1 SIMPLIFIED FUNCTIONAL BLOCK DIAGRAM OF RADC WIDEBAND RADAR

indicated improved dynamic range. Sidelobe levels ranged from -30 dB to -37 dB below the main response, depending on the position within the range window. As originally specified, sidelobes were to be 40 dB below peak; however, RADC decided to relax requirements since insistence on specifications would have delayed the upgrading program even further. As it was, the sidelobe levels of the new PC network were 10 dB better than the previously used equipment.

2. Linear Wideband Sweep Generator

RADC's decision to replace the existing magnetron wideband sweep generator was based primarily on the desire for better linearity (thus reducing time sidelobes). Another motivation was to avoid the problem of having to replace critical magnetrons which were no longer being manufactured. Watkins-Johnson Company was awarded the contract to manufacture the new all solid state sweeper. Delivery was promised for December 1973. In July, Watkins-Johnson Company personnel visited RADC for further clarification of the specifications. It seems that when bidding for this contract Watkins-Johnson had not fully appreciated many of the extremely stringent specifications.

The sweeper development program at Watkins-Johnson terminated, and an alternate plan to acquire the required sweeper was developed. The consensus among RADC, RCA, and RRI personnel was that an in-house sweeper development program should be undertaken. RCA was directed to purchase solid-state FM oscillators which could be incorporated in a wideband sweep generator to be designed and developed at the Site. Two Solid State Technology Company sweepers were received by RCA late in December, 1973. These proved to be extremely linear, i.e., better than 1 per cent over the 500-MHz sweep. Stability of one part in 10^5 was also measured. Due to time limitation, the sweeper development was limited to passive compensation only. Even so, sidelobe

levels on internal tests indicated 26 dB below peak response. Some chassis cleanup and repackaging preceded installation in the RFI cabinet in back of the antenna dish. Integration of the sweeper with the transmit/receive channels was successfully completed.

3. Up/Down Converters

Airborne Instrument Laboratories (AIL) received the contract to build new up/down converters. Again, the decision to replace these was made by RADC and was based on the desire to reduce range sidelobes and extend the operating bandwidth to 500 MHz.

The AIL-developed wideband UP/DOWN converters showed several problems during a number of acceptance tests. In the UP converter the output stage was saturating, while in the DOWN converter some RF switches did not provide sufficient isolation. Furthermore, the local oscillator lines exhibited excessive voltage-standing wave ratio. In late April 1974, acceptance tests of the AIL up/down converters were successfully conducted at both the AIL plant and at the Floyd Site. The RRI site representative witnessed these tests. These converters were subsequently integrated into the signal processing hardware and installed in the new antenna receiver room.

4. Transversal Equalizers

The existing transversal equalizers required replacement because of the planned 40-μsec pulsewidth and 500-MHz frequency sweep, rather than the 20-μsec, 250-MHz operation carried out early in the program.

Hazeltine designed and built new transversal equalizers. The acceptance tests at Hazeltine were very successful in that the unit demonstrated that any sidelobe can be reduced by 40-dB

with the transversal equalizers. It also exhibited excellent stability over 2 days, i.e., sidelobes did not change by more than 1-2 dB.

The transversal equalizers were tested at Hazeltine in November 1973 and, with the exception of a saturating amplifier, performed very well. Subsequently, the dynamic range was improved by modifying the output stage and the transversal equalizers were accepted at the Floyd Site towards the end of November.

5. Wideband RF Amplifiers and IF Amplifiers

The existing TWT RF amplifiers exhibited excessive amplitude and phase ripple across the operating band. Miteq, Inc., contracted to build transistorized wideband RF amplifiers having smooth amplitude and phase characteristics. Acceptance tests were successfully carried out, and the units were delivered.

Several IF amplifiers in the signal processing chain were found to have undesirable bandpass characteristics. Sage Laboratories, Inc., who received the contract to manufacture new units, delivered these after successful acceptance tests were completed.

6. Equipment Installation

Following the decision to terminate operation of the site, an effort was made to complete installation of the newly acquired equipment and to demonstrate operation of the wideband system at least once. Installation of all components in the RFI shielded cabinets was completed with the exception of two phase locked oscillators, .995 and 2.4 GHz, which had been ordered late in the program and had not arrived at the time of cabinet installation behind the antenna dish. On-site units were substituted. Initial transmission and reception tests were successful. However, some timing and range tracker problems ate into the remaining time so that it became obvious that it was

not possible to successfully demonstrate wide band operation before the site closing was to occur. For that reason, radar operation work was halted and termination procedures were initiated.

B. TRANSMITTER

The Floyd site radar transmitter amplifier chain used three stages of RF amplification with a goal of 40-μsec pulse width, and 10-MW peak power output. A nominal 500-MHz bandwidth and phase variation of ± 6 deg from linear over 80% of the bandwidth had also been specified for the transmitter in order that the swept frequency waveform provided by the exciter not be degraded. In the expectation that the desired phase response would not be achieved by unaugmented circuitry, provision was made for two techniques to linearize the overall transmitter phase characteristic.

One was an open loop technique in which the helix voltage of the predriver TWT (see Fig. 2) was provided with a preprogrammed correction signal utilizing the helix voltage phase modulation characteristic to tend to cancel the nonlinearity of the transmitter. The other was a feedback technique which compared a sample phase of the transmitter output with a sample (appropriately delayed) of the input and used any difference to modulate the helix voltage of the predriver TWT. A description of these methods is provided in Ref. 2.

During the months immediately prior to the RRI contractual period, RCA performed a series of evaluation tests on the transmitter.[3] These consisted of extensive measurements of the phase, amplitude, and gain as a function of frequency of the transmitter stages, singly and collectively. Point frequency and slow-sweep frequency measurements were made using a signal generator. Chirp (250-MHz LFM) measurements were also carried out with the radar exciter itself. At this time the pulse forming network

(PFN) used in the modulator for the final power amplifier (FPA) was supplying a video pulse suitable for a 20-μsec RF pulse.

The first activities involving RRI efforts directly were attempts to duplicate some of the earlier measurements; both to familiarize the new personnel with the equipment and to establish a better defined data base from which to make changes to improve performance. These measurements were restricted (for almost this entire reporting period) to point frequency and slow-sweep measurements since the timing circuits used for chirp generation were out of service due to the concurrent receiver system improvement program. Fig. 2 provides a simplified block diagram of the transmitter test configuration. Directional coupler test points 1 through 4 provided sample points for amplitude and phase measurements. A suitable length of cable was introduced into Line 1 for each phase test.

Examination of the initial overall amplitude response (Fig. 3) showed agreement with earlier site measurements, but considerable variation from the manufacturer's test data. The lower bandwidth of the site data, together with two frequency regions within the passband having amplitude droops of more than 3 dB and a generally ragged response, indicated that the FPA was not operating in a gain-saturated mode. First efforts were therefore directed toward obtaining saturated input to the FPA. The interstage connections between the amplifiers were examined to reduce losses (e.g., an attenuator between the driver and FPA, set to zero, was physically removed) and cabling was rerouted, where possible, to reduce path lengths. In addition, the operating voltages of the driver TWT were varied in order to obtain higher drive power output. The result of these changes was to provide some improvement in the shape of the amplitude response. There was considerable flattening of the overall response (the low frequency end had tended to fall off) and lessening of the droops at the expense of the peak amplitude which lay

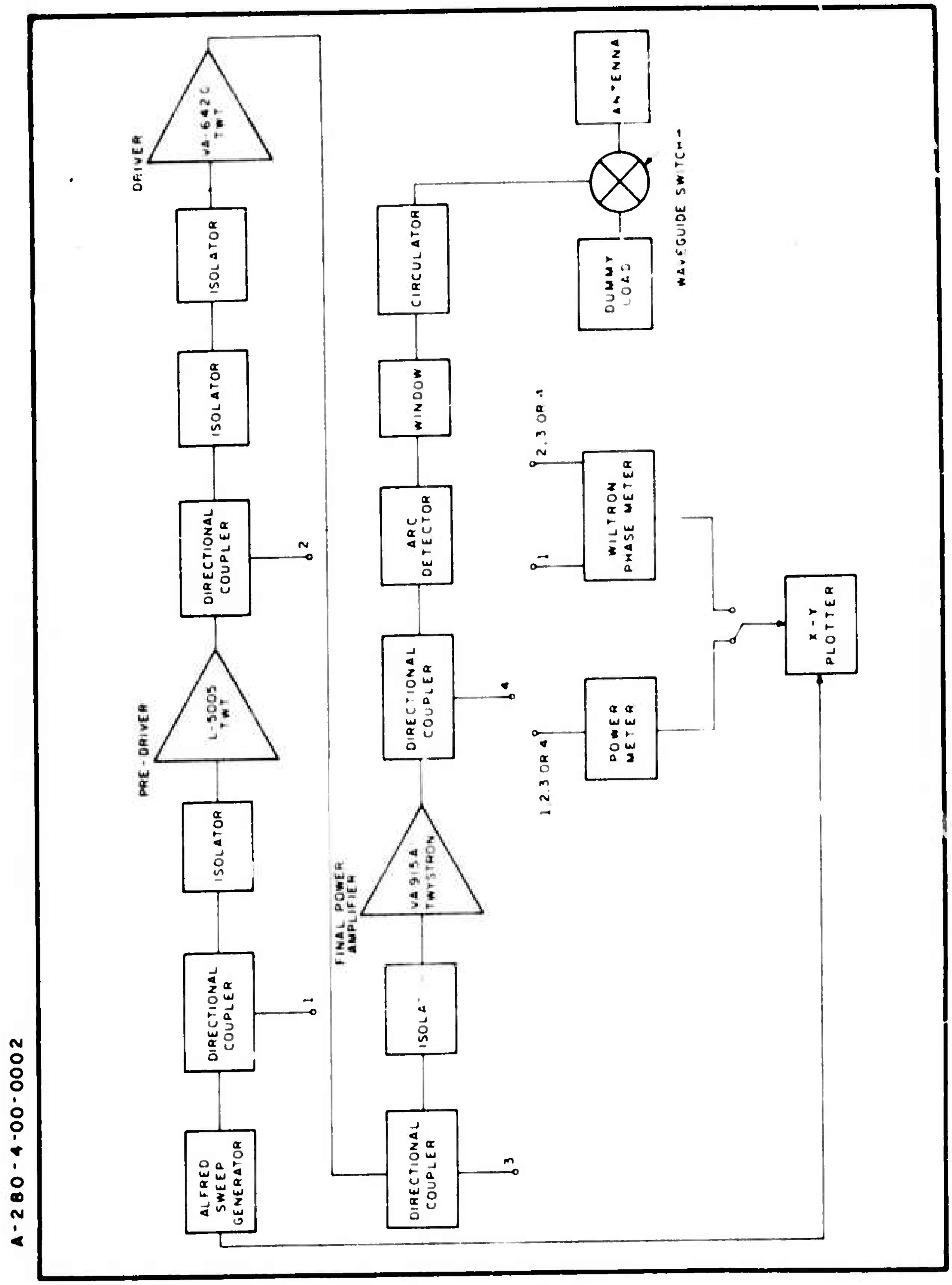


FIG. 2 SIMPLIFIED TRANSMITTER BLOCK DIAGRAM FOR AMPLITUDE AND PHASE MEASUREMENTS

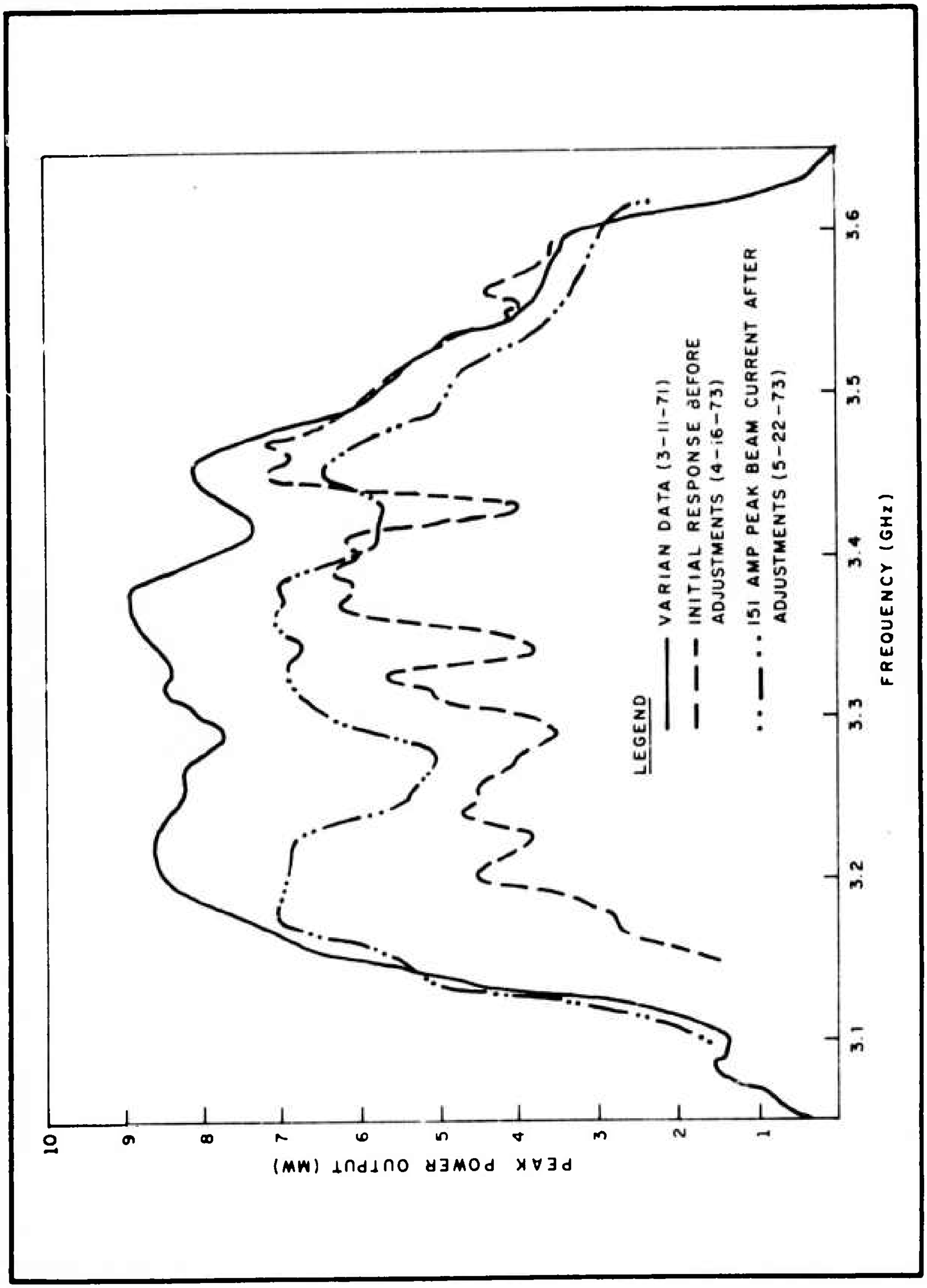


FIG. 3 TRANSMITTER AMPLITUDE RESPONSE IMPROVEMENTS

near the high frequency end of the band. Conversation with the FPA manufacturer, Varian Associates, elicited the information that the tube was sensitive to operating point, especially to that of the first focus solenoid. A series of parametric measurements was made varying the first-focus-coil current. The last displayed relatively little effect. It was found that operation was considerably improved by utilizing a first-focus-coil current of approximately 9 amp and a peak beam-current of 148 amp (up from 7.5 amp and 146 amp, respectively) indicated. While of lower indicated peak power, the curve shape of the amplitude response was becoming similar to the manufacturer's data. It should be mentioned that, all during this period, measurements were occasionally interrupted by transmitter shutdown caused by waveguide arcing. The arcing was especially prevalent when operating at frequencies near the high end of the nominal range. At that time the waveguide window located in the transmission line between the arc detector and circulator (Fig. 2) to provide pressure isolation for the sulfur hexafluoride (SF_6) dielectric gas suffered mechanical failure. Correspondence from the tube manufacturer stated that recent tests indicated the tube window could withstand the higher waveguide pressure. When the system was activated without the window it was noted that there was further improvement in the bandpass characteristic.

After additional measurements with the peak beam current set to 151 amp, the amplitude response of the transmitter was deemed minimally adequate for system use, and attention was directed toward phase measurements and the hardware aspects of widening the pulse width from 20 to 40 μsec.

The phase tests were performed in two areas: phase/amplitude sensitivity of the predriver for phase correction applications, and the phase linearity of the reference cables used in the phase measurements (joining Points 1 in Fig. 2). It

was found that a voltage swing from +20 to -15 volts around the nominal helix voltage of the the predriver yielded sufficent phase variation to compensate for the approximately 60-deg peak-to-peak measured phase nonlinearity of the transmitter (Fig. 4). The predriver incremental output variation for this helix voltage swing was less than $\pm$ 0.1 dB. Other tests showed excessive phase nonlinearities in the reference phase cables. They were alleviated by replacing these cables with specially acquired semi-rigid coaxial cables having a much more linear phase characteristic.

Phase measurements were now made on the transmitter while varying the first-focus-coil current and the peak-beam current. As with the amplitude response, the best operation was secured at higher coil and peak beam-currents than had been previously used. It was felt that the tube was probably operating closer to the manufacturer's test levels under these conditions, and the tube was providing high gain and therefore operating more nearly saturated than earlier. (This was later borne out when it was necessary to recalibrate the current meters upon the introduction of the 40 μsec pulse width, and the optimal peak-beam current was measured at 146 amp, the same value achieved by Varian.) At this time the waveguide arcing problem became so severe that testing was stopped to permit refurbishing of the waveguide components and to allow other transmitter improvements to be made.

One area in which the arcing seemed persistent was in the high power circulator. One section of ferrite in the center of the circulator was observed to be displaced further into the waveguide than other sections and it appeared that some arcing had occurred on this displaced section. It was finally determined that the unit was not responsible for the arcing.

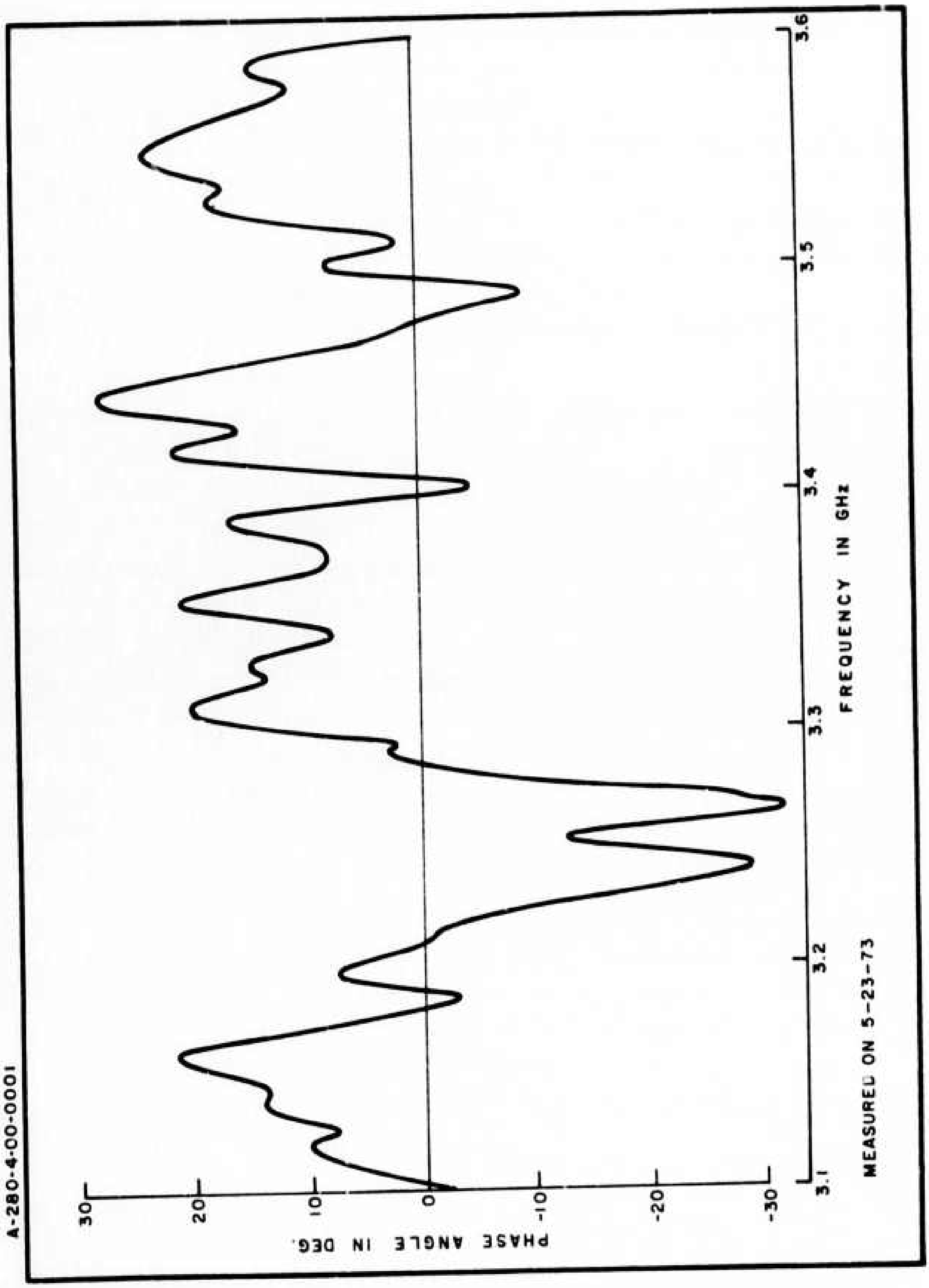


FIG. 4 MEASURED TRANSMITTER PHASE NON-LINEARITY

The FPA pulse width was widened by increasing the length of the PFN inductance and adding additional capacitors along the coil. A video pulse commensurate with a rectangular RF pulse of 40 μsec was achieved after balancing the L/C ratios along the PFN. The increase in average power with pulse width required recalibration of the beam-current meters and led to the recognition of errors (high readings) in peak beam-current readings. All the meters were recalibrated with one result being the previously mentioned more nominal value of the Twystron peak beam-current.

Following the expansion of the PFN to provide the 40 μsec pulse width, a series of problems prevented significant further progress. The dominant problem remained waveguide arcing. Although the waveguide transmission line was pressurized with 26 psig of SF_6 dielectric gas, the arcing problem had persisted. Three conditions were noted which would tend to permit contamination of the gas, particularly since it had been necessary to open the waveguide system repeatedly during the testing period. First, there was no convenient method of purging air from the transmission line either before or during the gas pressurization process. Second, the gas remained stagnant in the lines after they were filled; except for the klystron window cooling flow, the gas in the waveguide was not circulated. Finally, no method for drying the gas in the system existed.

To alleviate these problems, (1) a purging spigot was placed in the highest-point in the waveguide system, (2) the klystron window cooling lines were rerouted to provide gas circulation through the waveguide as far as the dummy load, and (3) components for a gas drying system were obtained.

For a while following the installation of the circulating SF_6 system, along with an SF_6 scrubber, the sytem exhibited

many fewer arcs. However, after a few days, the problem re-occurred. Disassembly of the waveguide run from the final amplifier to the dummy load showed that arcing had taken place at the waveguide flanges. Remachining and cleanup of the parts was followed by careful reassembly. As part of the reassembly, a procedure for tightening flange bolts to the proper torque level was established since it had been found that some bolts had become loose (most likely due to temperature changes). After this reassembly, arcing ceased to be a serious problem.

Although waveguide arcing was the major problem, it was also noted that the transmitter would turn off occasionally without showing indications on the interlock display panel as to cause of turn-off. It was determined that self-resetting relays were used in several locations. To improve operations, a latching interlock system was installed in four of the more critical sensors: arc fault, VSMR fault, body overcurrent, and beam overcurrent.

Another problem which occasionally appeared was that of the system crowbar actuating, apparently due to an excess current flow in the high power modulator. Finally, during operation, a loose PFN lead touched and welded itself to the PFN frame, thereby shorting the primary winding of the pulse transformer to ground. The inverse diode then was forced to disipate full PFN power and failed shortly thereafter. Following replacement of the diode, it was noted that the transmitter would go off the air at frequent intervals with high voltage DC over-current being the indicated fault. Tests indicated that the faulting item was the thyratron which was going into continuous conduction. It was replaced, but the problem persisted. The second thyratron was replaced with similar results. The problem turned out to be that the replacement thyratrons, though of the same type number, were a different model which required that

cooling air be blown on the grid and anode structure. The original thyratron no doubt was damaged due to the PFN being shorted to ground. It appears in retrospect, however, that some addtional cooling of this tube might well have been in order, since the transmitter was more stable with the added cooling.

Improved transmitter stability permitted additional phase measurements to be made. An attempt was made to program the predriver helix voltage waveform using an available FM exciter so as to compensate for the approximately 60° phase excursions introduced by the FPA. The results of this open loop approach were to reduce the phase excursions to $\pm$ 3°. The age of the exciter proved a problem when it was found the GE voltage tunable magnetron used in it was no longer manufactured. Two Varian VTMs were obtained as replacements, and after the demise of the GE tube, testing of the phase characteristics of the entire transmitter chain indicated a repeat of the measurements previously made, that is, a phase deviation of $\pm$ 3 degrees from linear with passive compensation only. Timing jitter prevented a reasonable measurement of the combination of active and passive compensation. However based on observed results, it was felt that in combination with the transversal equalizer, the transmitter could have been successfully integrated into a low sidelobe level system.

C. RADAR SYNCHRONIZER

Initial evaluation by RRI personnel revealed the radar synchronizer to be among those radar subsystems most seriously in need of major improvement. This was concurred by RCA personnel who, in the course of performing detailed examination of the unit, found that the synchronizer suffered excessive jitter. Several deficiencies, all of which were very likely contributors to the jitter problem, were noted. Some of the major deficiencies

found were (1) intermodule wiring of the unit lacked consideration of shortest possible lead lengths, sufficient signal ground returns, and high frequency shielding to eliminate RFI from external sources and inter-conductor signal cross coupling; (2) several unused inputs to logic gates were left floating and thus susceptible to pickup; (3) the delay lines needed to increment the basic clock period (100 nsec) could not be cut with sufficient accuracy to provide the desired 0.5 nsec granularity; and (4) the plating on several of the module connectors was worn enough that adequate connection could not be assured. The jitter problem was further complicated by the nonavailability of consistent wiring diagrams.

Discussions, with RADC, RRI and RCA personnel in attendance, resulted in the decision by RADC to perform a major upgrading modification to the radar synchronizer. The unit was completely disassembled by RCA personnel, and those elements which could be reused with adequate reliability were refurbished while the more critical elements were eventually replaced with new, and more reliable, high speed logic. This upgrading effort was instituted in a two phase plan. Disassembly and refurbishment of the entire radar synchronizer was accomplished in the initial phase resulting in an operational unit with significantly improved performance which was available for use during the period prior to the installation of the new high speed logic unit in the latter phase.

After disassembling the synchronizer, RCA replated the etched connectors on several of the logic modules. During the process of rewiring the modules, additional signal ground returns were provided and bypass capacitors were installed on power supply inputs. All unused inputs in the several logic

decision elements were biased to the appropriate logic levels to eliminate false triggering due to pick up of spurious signals. In addition to the upgrading of the various logic modules, the entire synchronizer chassis was completely rewired.

During this phase of improvement effort RCA designed and built a unit utilizing logic circuits operating at 320 MHz to provide the required 0.5 nsec granularity. This unit, implemented on a single strip-line platter to provide total isolation from RFI, was built to replace a section of the synchronizer containing the critical timing responsible for the positioning of the transmit and receive sweep generator pulses and the pulse compression triggers within 0.5 nsec. This unit, which utilized proven RCA techniques, was completed and successfully tested under RADC and RRI observation without any major problems and was subsequently installed in the radar synchronizer at Floyd site. With the installation and interfacing of this unit, the overall performance of the synchronizer was further improved so that the jitter was less than the least significant bit of the synchronizer and was undetectable when displayed on an oscilloscope. The synchronizer very successfully met the specified requirements for an operational system.

III. COMPUTER CONTROL OF THE RADAR

A. SUMMARY OF THE COMPUTER STUDY

1. Introduction

The study of the required computer capability was undertaken by RRI as part of the general upgrading program for the Floyd Site Wideband Pulse Compression Radar (WPCR), with the objective of selecting a computer compatible with an operational environment for eventual installation at the facility. In the computer study the first step was to determine all the required, as well as desired, computer functions regardless of any particular computer configuration or of cost considerations. Sets of appropriate computer functions were then combined to form three options of varying operational complexity. Next, a number of computers and their characteristics were examined to allow matching of computers to the functions associated with each option. Finally, the costs of equipment purchase or lease, programming, and interface design and construction were compiled and estimated for each of the computers in each of the options. No estimates were made of the requirements for real-time radar imaging; however the growth potential of computer configurations was examined for this capability. A summary of the approach and the findings of the computer selection study follows.

2. Options of Complexity

Three options for upgrading the Floyd Site computer (at the start of the Technical Assistance Program, a Digital Corporation PDP-1 with 4K of memory) were considered, each representing a different level of operational complexity. An attempt was made

to match the functional requirements to the particular option considered. The first option was the most complex, from a functional as well as from an operational standpoint. It would be chosen if the Floyd radar were to go on a routine operational basis with rapid data turn-around, and with 5 to 10 satellites tracked per week. Short countdown and set-up times would be desired to respond rapidly to Air Force requests for tracking and identifying satellites immediately after launch.

The second option would be to operate the Floyd radar in a less ambitious manner than that of Option 1, i.e., remain in an experimental status but with extended capabilities over the presently existing ones. The mission support level would be from 2 to 5 satellites per week, with data from only a few of those missions being reduced.

Option 3 would be chosen if the Floyd radar were to continue operating in a manner similar to its recent past with only one to two missions supported per week. It was felt that under these circumstances it would be desirable to upgrade the computer capability just to improve the data quality. The functions planned for the three options are outlined in the Appendix.

3. Computer Selection

Initially, a number of computers were chosen* and attempts were made to determine whether they were reasonable candidates to perform the required functions. At this point their utility for the various options was not considered. For the real-time functions, operation time was the most important

* Information used in selecting computers was obtained in the Auerback Standard EDP reports, in manufacturers' literature, and from computer company representatives.

factor; for non-real-time functions, core size was the overriding consideration. Then, computers were eliminated because their speed, size restrictions, lack of expandability, or cost made them less attractive than the following computers which became serious candidates: Digital Equipment Corporation PDP-11/45, Data Craft DC 6024/1, Xerox Data Systems Sigma 5 and Sigma 3, and the IBM-370-135.

Next, generalized computer configurations were defined assuming that the algorithms were operating with a 32-bit machine. Memory requirements of the 16- and 24-bit word computers were increased by 50% over those of the 32-bit word computers in order to cover the additional words required for single and double precision floating point variables. It would be impossible for the actual computer systems to contain the same components, for each manufacturer had slightly different types of equipment and sold or leased the equipment in different quantities. A system closest to the generalized configuration was always chosen unless it was more economical for a particualr machine to be better equipped than required. The computer requirements for each of the candidate computers are listed for each option in the Appendix.

4. Conclusions

Table VI-A-1 of the Appendix summarizes the costs of improving the WPCR on-site computing capability for each of the three options that were defined. The costs of hardware interfaces are included. Computer site preparation costs, a nearly fixed amount independent of any particular system, are not included. Where the cost of yearly lease is not listed, it is because that computer manufacturer does not lease its computers. The programming and hardware interface work costs are based on average rates for Riverside Research Institute programmers, engineers, and support staff and include allowance for overhead

and fee. For each option, the growth potential column refers to the feasibility of expanding the computer configuration to that of the next higher option.

In view of Syracuse University Research Center's (SURC) investigation of the possibility of real-time radar imaging at the radar site, the growth potential column indicates the feasibility of expanding the computers to configurations which would be able to perform real-time radar imaging. Table VI-A-2 of the Appendix indicates the equipment and cost that would be necessary in order to implement this additional function. The table is included merely to provide an estimate of the added costs for this function (man-power costs and the cost of possible graphical display equipment are not included) and to show which computers would remain possible choices if real-time imaging were to be implemented.

5. Recommendations

The following recommendations were made:

If it is decided to undertake a minimal upgrading (Option 3) to achieve higher quality data than is presently available, while still retaining the present very limited operational status, the PDP-11/45 (at a total purchase price of $154,000 including computer interface materials and labor, and programming costs) is suggested because of its speed, excellent growth potential (which would allow possible expansion at a later date to a more complex option), and low cost. For similar reasons, the PDP-11/45 (at a total purchase price $205,000) is also recommended if a more substantial upgrading is to be carried out (Option 2).

If the radar is to go on a routine operational basis with rapid data turn-around (Option 1), the PDP-11/45 is still very attractive, particularly because of its low cost (total

purchase price of $446,000). However, the Xerox Data Systems Sigma 5 (total purchase price $687,000 or total yearly lease of $416,000 for the first year including computer lease, interface materials and labor, and programming costs) could easily expand into a computer capable of real-time radar imaging. Real-time radar imaging could be possible on the PDP-11/45; but since the maximum core available on PDP-11/45 is less than that required for efficient radar imaging, the number of images per satellite pass would not be as great as if this function were performed on the Sigma 5. The fact that the programs for radar imaging exist on a Sigma 5 would lower the programming cost and thus ameliorate the price difference between a PDP-11/45 and the Sigma 5. For these reasons, if optimum real-time radar imaging is the current objective, or is of future importance, the XDS Sigma 5 is recommended.

6. Study of Possible Off-Site Location Of Computer

A study concerning the implications of locating a computer away from the Floyd Radar Site was also performed. The study estimated the additional interface equipment, system implementation time, operation, computer scheduling, and costs associated with a remote computer configuration of the type required under the previously defined Option 1. Because of the high initial installation costs, the permanent incremental costs and, in particular, the problems associated with integrating a remote computer with the Floyd radar, it was not recommended to implement operation with an off-site computer. A brief summary of study[4] follows:

Because of the wide bandwidth of the Floyd radar data, the data rate is high (400 range bins * 4 samples/range bin * 8 bits/sample * 70 pps + parity and clock bits > 1 M bits/sec), and because coaxial cables would not be feasible, a

microwave link would be interfaced with the radar. The additional initial cost of installation and checkout of the microwave link, and implementation of the functions required under Option 1 would be $253K for hardware and labor. Additional staff costs (2 professionals) would be approximately $100K per year over those required with an on-site computer.

Checking out the two-way microwave link, the computer/radar interface, and the computer algorithms would require communication between computer and radar personnel. With the remote siting such communication would be complicated and would lead to inefficiencies and time delays. Once the computer was interfaced with the radar, observation of between 5 and 10 satellite passes would be scheduled per week. The inefficiencies introduced by the remote location of the computer could easily force the number of scheduled satellite observations to be decreased and lessen the ability of the Floyd Radar Site to be responsive to Air Force requests for satellite tracking and identification.

B. XDS SIGMA 5 COMPUTER

A major development during the Technical Assistance Program was the acquisition of a third-generation computer for the Floyd Site Wideband Radar. RRI, by virtue of its involvement in the AMRAD radar program, was able to arrange the transfer of the XDS Sigma-5 computer from the AMRAD facility at White Sands Missile Range, New Mexico, to the Floyd Site. In the latter part of November 1973, RRI was directed by the White Sands Missile Range to terminate activities at the AMRAD facility. RRI had had responsibility for scientific direction of the AMRAD program for several years. The AMRAD radar was a highly complex measurements radar, utilizing an XDS Sigma-5 computer with special-purpose interface equipment for data collection and waveform control. A major portion of the computer equipment

was leased by RRI from Transamerica Corporation, a smaller portion from XDS. Both leases had a purchase option clause and it was felt by RRI that the accumulated equity should not be lost to the Government as a result of a lease termination particularly in view of the known need for a computer at the Floyd Site. (In the computer study, RRI had concluded that an XDS Sigma-5 was eminently suited for the Floyd Radar.) Accordingly, RRI notified cognizant personnel at RADC of the possible availability of the computer. A check with WSMR authorities, as well as the Defense Supply Agency (who disposes of government ADPE), showed that there would be no objection to a transfer. Transamerica and Xerox Corporation also indicated agreement. Shortly thereafter, upon receipt of written agreement from WSMR and DSA, RADC directed RRI to continue the lease and arrange for the transfer and installation of the Sigma-5 at the Floyd Site.

Since the AMRAD facility was to be shut down in the month of December, swift action was necessary. Hence, RRI arranged for the installation of a computer floor at Floyd in the latter part of December. Floor layouts for the equipment and power distribution were also generated. Parts and wiring for the power distribution system were purchased by RRI and installed by RADC personnel. The actual move took place in early January, the computer arriving at Floyd on 14 January. Subsequently, XDS personnel inspected the computer and found only minor damage. (An exception to this was the line-printer, which was dropped by the movers at AMRAD during loading and required factory repairs.)

Several delays were encountered with the installation of the Sigma-5 computer. A replacement line-printer for the one damaged during the move from AMRAD was not received until 22

February. In the meantime, air conditioning requirements were defined and Griffiss AFB maintenance personnel were to install the required ducting and recondition the air conditioning equipment. Due to scheduling difficulties, this work was only partially completed. RRI and RADC site personnel carried out actual installation of the ducting in order to meet the computer installation schedule. XDS personnel started interconnection of the Sigma-5 computer on 25 March 1974. Shortly after initial application of power it was discovered that the high-speed tape unit and the RAD were inoperative. After considerable trouble-shooting a faulty power supply was found to cause the tape unit problem, and it was determined that the entire RAD drive assembly would require replacement. When the new drive was finally installed, it was found that certain tracks were in-operative. A new disc was ordered by Xerox, and eventually after correction of some minor memory problems, the Sigma-5 became operative on 25 April 1974.

C. INTERFACE DESIGN

During this reporting period RRI completed a preliminary design of a Radar Control and Data Processing System (RCDPS) to be interfaced with the WPCR at Floyd Site. The RCDPS utilized an XDS Sigma 5 computer and other special purpose digital equipment obtained by RADC from the AMRAD facility at the White Sands Missile Range. This system was designed to provide the WPCR with the extended capabilities of (1) pre-experiment ephemeris sorting and pointing data table generation; (2) automatic radar calibration and check-out; (3) real time radar control, data display, and signature data acquisition and recording; and (4) post-mission data reduction and diagnostics. The system offered significant enhancement of the WPCR capabilities in the SOI program, and provided increased flexibility

of operation of the radar as well as rapid turn around on mission data processing (on-site). The latter is extremely important for diagnostic purposes in an operational measurements radar activity and could have ultimately led to near real-time image formation.

The system, under program control and interacting with operator command signals, provided automatic execution of the many necessary functions associated with radar control and data processing. (For a more complete description of these functions refer to Table III-A-1 of the Appendix.) In planning the development of the initial system (in both hardware and software requirements) consideration was given to the accomplishment of two major objectives. The first, to provide in a short time, without interrupting on-going radar activities, an economical system consistent with a conservative budget. The second, to provide a highly reliable system offering ease of expandability in meeting additional future requirements. To meet these objectives the system design included the use of as much of the specially designed equipment from the AMRAD data system as possible. A relatively small amount of modification was required in some cases to tailor the equipment precisely to the Floyd Site requirements. In addition, a moderate amount of newly designed hardware utilizing XDS logic modules (already on hand at Floyd Site) was required.

A brief description of the system is presented in the following paragraphs in three categories; (1) Control and Displays, (2) Data Acquisition and Recording, and (3) Diagnostic Test Equipment.

1. Control and Displays

All operator control functions required in the operation of the system would be provided by way of push button switches on the system control console, and those required for

remote control would be provided on the operator's console in the control room. These switch functions would be encoded in a single computer word (System Control Word) to be interrogated once each pulse repetition period (PRP) by the System Control Program . These controls consisted of (but not were to be limited to) functions such as: System Operating Mode (Mission, Amplitude Calibration, Phase Calibration, or Sphere Calibration), Data Modes and Rate Options, Recorders On or Off, Data Monitor Selections, Trackers (Range and Angle) on or off line, Tracker Modes, Bandwidths, etc. This control information would be input to the computer memory via a DIO register.

Radar control functions, such as antenna positioning and target sample window positioning would be effected by outputting control words to independent Direct Input Output (DIO) registers which would interface with the appropriate radar subsystems.

Several data words would be output to DIO display registers each PRP to drive displays on the operator's consoles. These displays would be standard decimal image projection type units which would present to the operator(s) such information as target range, azimuth, elevation, velocity, altitude, radar cross-section, etc., as well as radar calibration constant and miscellaneous status information.

2. Data Acquisition and Recording

The RCDPS would provide real-time acquisition and recording of digital data during each radar pulse repetition period. Auxiliary data (consisting of antenna azimuth and elevation, time and miscellaneous status, as well as amplitude and phase data from the Δ azimuth and Δ elevation signals in both the vertical and horizontal polarizations) would be sampled

and input once each PRP. This data would be input through special DIO registers into the computer memory to be recorded and, in the case of angle difference data, to be utilized in the angle tracking algorithm.

Signature data (amplitude and phase measurements on the vertically and horizontally polarized sum signals) would be input through the Direct Memory System (DMS) via the Data Acquisition System (DAS) which provides slowed-down buffering in its high-speed memory (HSM). This data represents the bulk of the data throughput of the system. To accomplish the objectives described previously, the DAS would be configured utilizing, as nearly as possible, the equipment configuration of the existing AMRAD DAS. Although the use of this equipment would impose some limitations in initial experimentation it would, however, provide flexibility in sampling options and offer ease of expandability, as well as allowing parallel operation totally independent from the currently used Data Handling Equipment (DHE.) The major limitation would be in the size of the HSM. The HSM could store up to its limit of 240 words (32 bits per word) of data and would then be dumped completely before new data could be stored. (This limitation would not have seriously compromised RADC objectives in SOI experimentation. Several sampling options, with fewer samples per PRP than the present DHE capacity, would have been provided and would have been selectable under software control.)

The video input to the DAS would occur on two separate channels. This would require a minor modification to the existing WPCR Signal Processor providing separate outputs from the log amplifier and phase detector. The output from the phase detector had to be prior to the 100 μs delay. The DAS would

provide parallel sampling channels for amplitude data and phase data simultaneously. The video input to each channel would consist of two sequential pulses representing vertically and horizontally polarized sum signals. The video pulses would be sampled in both channels simultaneously utilizing 7-bit 10 MHz Analog-to-Digital Converters (by Computer Labs) which were also available at RADC among the equipment from AMRAD. The DAS would provide an additional bit with each 7-bit ADC sample which would identify the sample as vertical or horizontal data. The resulting 16 parallel bits of data occurring at each sample time would be alternately stacked in the left and right half-words of sequential 32-bit word locations in the HSM until the sampling for one PRP was completed. Upon input of the final sample the HSM Dump process would be initiated and would continue under control of the DMS until all data previously stored in the HSM had been transferred into the computer memory.

All data would be recorded on standard 9-track, ½-inch computer tapes utilizing the Sigma-5, 120 KB tape recorder. This would eliminate lengthy playback and reformatting procedures required when using multi-track instrumentation type recorders. It would, in addition, eliminate the need for interface equipment for such a recorder, as well as the maintenance of this equipment. The use of the standard Sigma-5 recorder would result in rapid post-mission data processing, and would enhance the overall system reliability by reducing the number of steps through which the data would be processed.

3. Diagnostic Test Equipment

The RCDPS would provide certain self-test features to allow for routine checks on the critical hardware contained in the various data I/O channels. A data monitor would also be provided for selected real-time data monitoring as well as for pre-mission calibration set-ups and diagnostics.

The major self-test feature would provide for automatically checking (under Central Processing Unit (CPU) control) all cells in the High Speed Memory within the DAS. Special DIO Test Registers would allow substitution of test data in place of the real data from the Analog to Digital Converters (ADC's) when this diagnostic routine was selected. The CPU would output test patterns to these DIO registers and check the data input via the DMS against standard formats. The results would be listed on a print-out. In addition to this feature, all DIO registers (control, display and data) would be provided with two-way transfer capability. This would allow each register to be loaded with test words and subsequently read for verification under CPU control when desired.

The data monitor (previously used at AMRAD) would be linked to the computer via a second channel on the DMS. The System Control Program would output selected data continuously to the data monitor when requested. The monitor, through thumbwheel switches, would provide selection of any twelve full data words per record for display on the System Control Console. The monitor would also count and display the total number of data words per record. This device would prove to be very valuable as an aid in calibration set-ups and in routine maintenance.

D. PROGRAMMING

With the acquisition of the XDS Sigma-5 system, plans were made for the expansion of computer functions in the areas of target acquisition, data collection, radar calibration, and diagnostics. Three options were considered and their interaction with the computer and radar hardware were studied. Option 1, the most ambitious, would consist of:

1. Premission Functions: Sorting of satellite ephemerides and generation of pointing data. Full calibration and check-out by computer.

2. Real-Time Functions: Acquisition. Computer range track. Computer angle track. Data recording directly onto computer tape. Reacquisition based on track history. Assorted display functions.

3. Post-Mission Functions: Computation of range, azimuth, and elevation residuals. Computation of narrow and wideband radar cross section histories. Generation of wideband digital range-time-intensity plots. Updata of orbit based on completed pass.

Under Option II, no computer angle tracking, reacquisition based on track history, and post-mission orbital update would be available. Further reduction of capability would take place under Option III. No computer range tracking would be performed and only very limited post-mission diagnostic processing would be available. In fact, only clean calibrated data tapes would be generated.

Along with studying the types of computer programs that would be needed to upgrade the radar system, the type of computer monitor software (available from XDS) that would be implemented was determined. The Real-Time Batch Monitor (RBM) was chosen because RBM is most suited to controlling a real-time

system in which batch submission is required. On April 25, after the computer hardware had been interconnected, RRI and XDS personnel performed an RBM system generation. At this point, the XDS Sigma-5 became operative.

IV. BORESIGHT TARGET

The Floyd radar had no internal test provision which included the full transmitter chain. However, in order to align the transversal equalizers so as to achieve the required time sidelobe response from the received signal, the fully operating radar should be included in the test loop. To perform this function, the equivalent of the return from a point target located at a range corresponding to a time interval not less than the transmitted pulse width was required. This minimum delay was necessary since the center of the compressed received pulse was preceded and followed by sidelobes forming a pedestal equal to the pulse width, and it was the amplitude characteristic of the pedestal which was of interest. An additional constraint was that any spurious or interfering phenomena be kept at a level lower than that to which the sidelobe performance was to be measured. For the Floyd radar, the transmitted pulse width was 40 μsec, and the required time sidelobe level was -40 dB.

The attainment of a nondispersive time delay of 40 μsec by artifical means (e.g., acoustic delay lines, long cables, etc.) did not appear feasible. The approach chosen, therefore, was to establish a radar target at a suitable range having sufficient radar cross section (RCS) to yield signal-to-clutter, noise, and spurious return levels to permit the desired measurements. The choice of a site required, in addition to the range delay corresponding to the pulse width, a delay of 60 μsec to allow for duplexer recovery. Thus, the resultant minimum range for the test target was approximately 15 km.

RRI initiated a search for a target location by examining contour maps of the Rome/Utica region. A number of ground profiles along possible boresight azimuths were constructed from the maps, and estimates of clutter and multipath signals were obtained. (The accuracy of such estimates is somewhat questionable because of the uncertainty in the knowledge of ground reflectivity and antenna sidelobe structure.) Likely azimuth bearings were thus found. RRI then performed on-site examinations. A potentially useful site for a target location was found 21.1 km from the radar at an azimuth of 146°T. This site was owned by the Consolidated Gas Supply Corporation and contains a communications tower suitable for the mounting of a reflecting plate. Such a plate was already attached to the tower, but its location would not have interfered with the Floyd activity. Contacts with representatives of the gas company resulted in receipt of permission to utilize the tower for mounting a test antenna.*

A profile drawing of the ground elevation joining the Floyd site and the proposed test site is shown in Figure 5. On the figure are also shown the line of sight joining the center of the Floyd antenna to the top of the test site tower, as well as a line representing the lower first null of the antenna pattern and a line corresponding to the lower 3 dB point of the pattern of a reflector aimed at Floyd site, having a one degree beamwidth. Although the figure does not include earth curvature, the possibilities for multipath interference are evident.

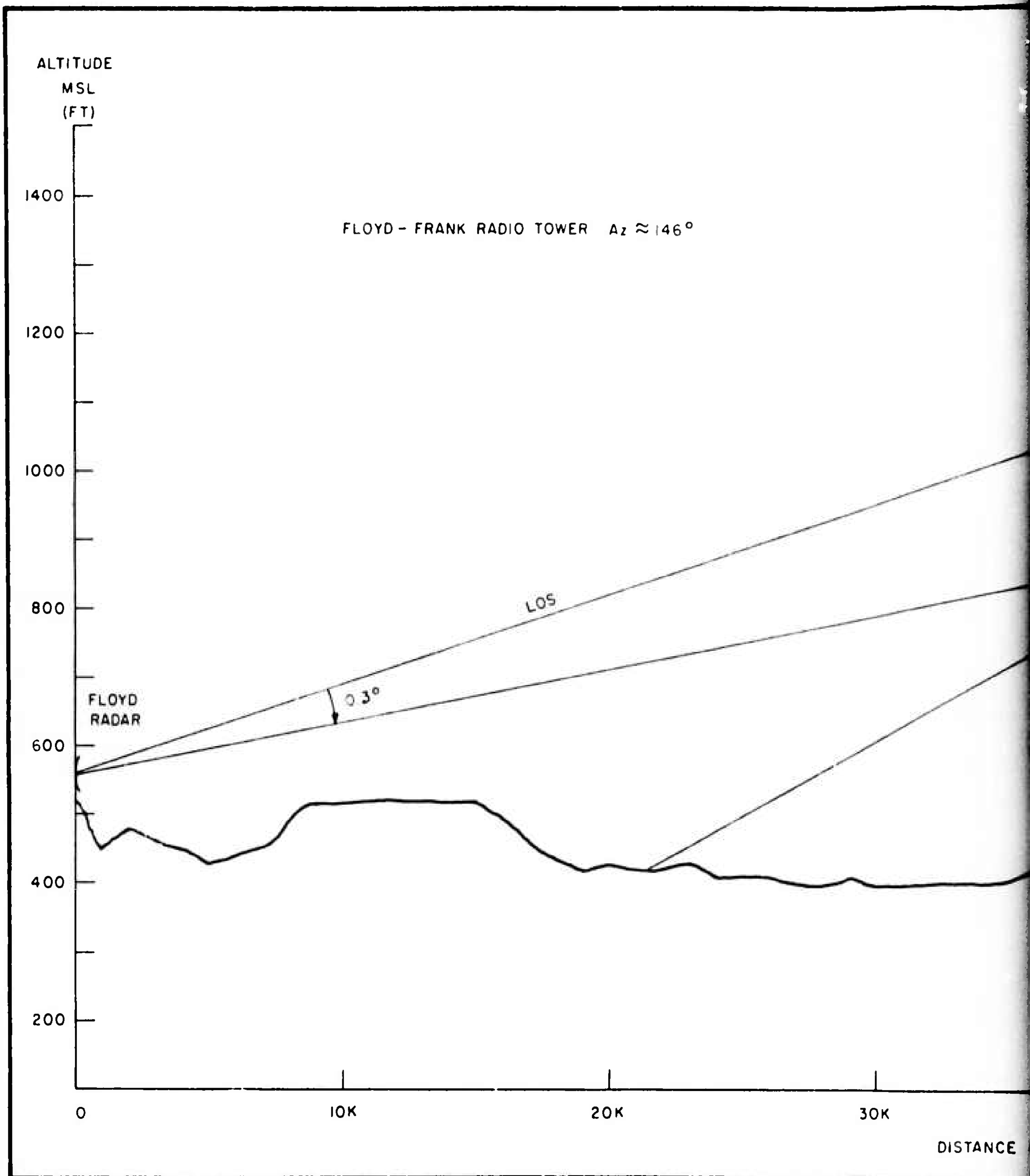
An estimate was made of the necessary RCS to be provided by the test target based on an assumed ground reflectivity (σ^0) of -20 dBsm per square meter. (This value was chosen as being representative of data obtained from clutter measurements of terrain similar to that surrounding the Floyd site and for

* Letter from J.E. Wallace of Consolidated Gas Supply Corporation, Clarksburg, West Virginia, to W. Both of RRI, January 22, 1974.

grazing angles below 10 deg[5].) At the range of the test target, with the beamwidth of the Floyd antenna (~0.3 deg), the clutter cross section was expected to be approximately -5 dBsm. In order to secure a signal-to-clutter ratio of 45 dB at the leading edge of the pedestal of the compressed pulse, a target RCS of approximately +45 dBsm would be required. This RCS would be obtained by a reflector constructed of a rectangular plate having an area of approximately 4.6 sq. m. While several possible configurations of the reflector were contemplated (variations in aspect ratio to effect desirable vertical and horizontal beamwidths, construction details, etc.) detailed design was delayed until quantitive clutter and multipath measurements were taken.

In order to evaluate the magnitude of the multipath and clutter problems, a test plan using a portion of the transmitter, the antenna, some spare receiver components, and a test reflector was evolved. With the equipment connected as shown in the block diagram of Figure 6 and a square corner reflector with a two-foot side length to be located at the test site, it was expected that a coarse quantative measurement of clutter and multipath signals could be made. The configuration permitted pulse width versatility to be achieved, with a useful range of from 40 μsec to 2 nsec (1 foot). For the test geometry, the minimum expected signal-to-noise ratio from the corner reflector return was to be greater than 40 dB. Prior to the curtailment of the program, the components shown in the diagram were assembled and tested, and indicated proper qualitative performance. Time did not permit quantitive measurements using the corner reflector.

A



B-280-4-00-0007

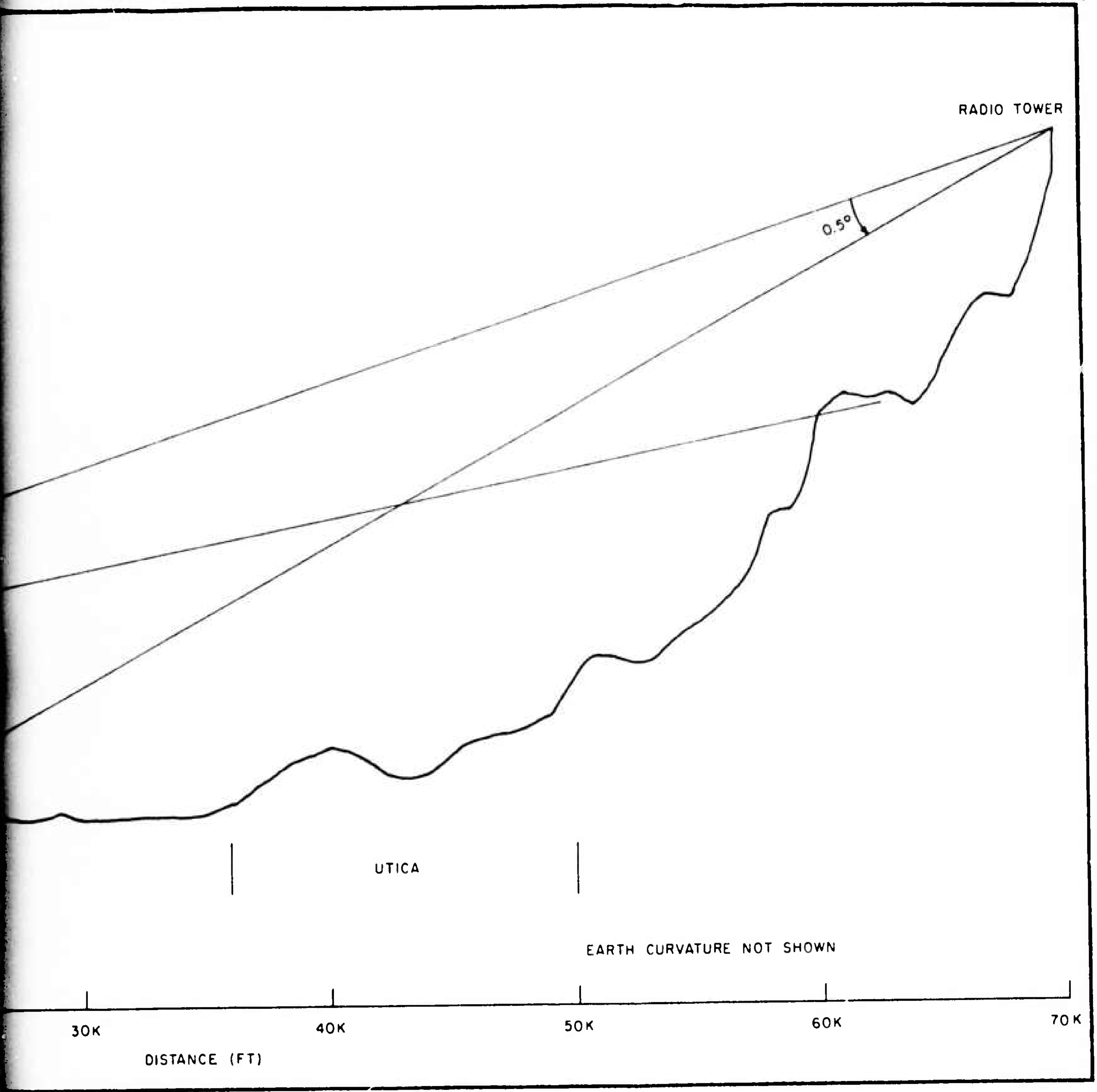


FIG. 5 GROUND PROFILE ALONG LOS TO TEST SITE

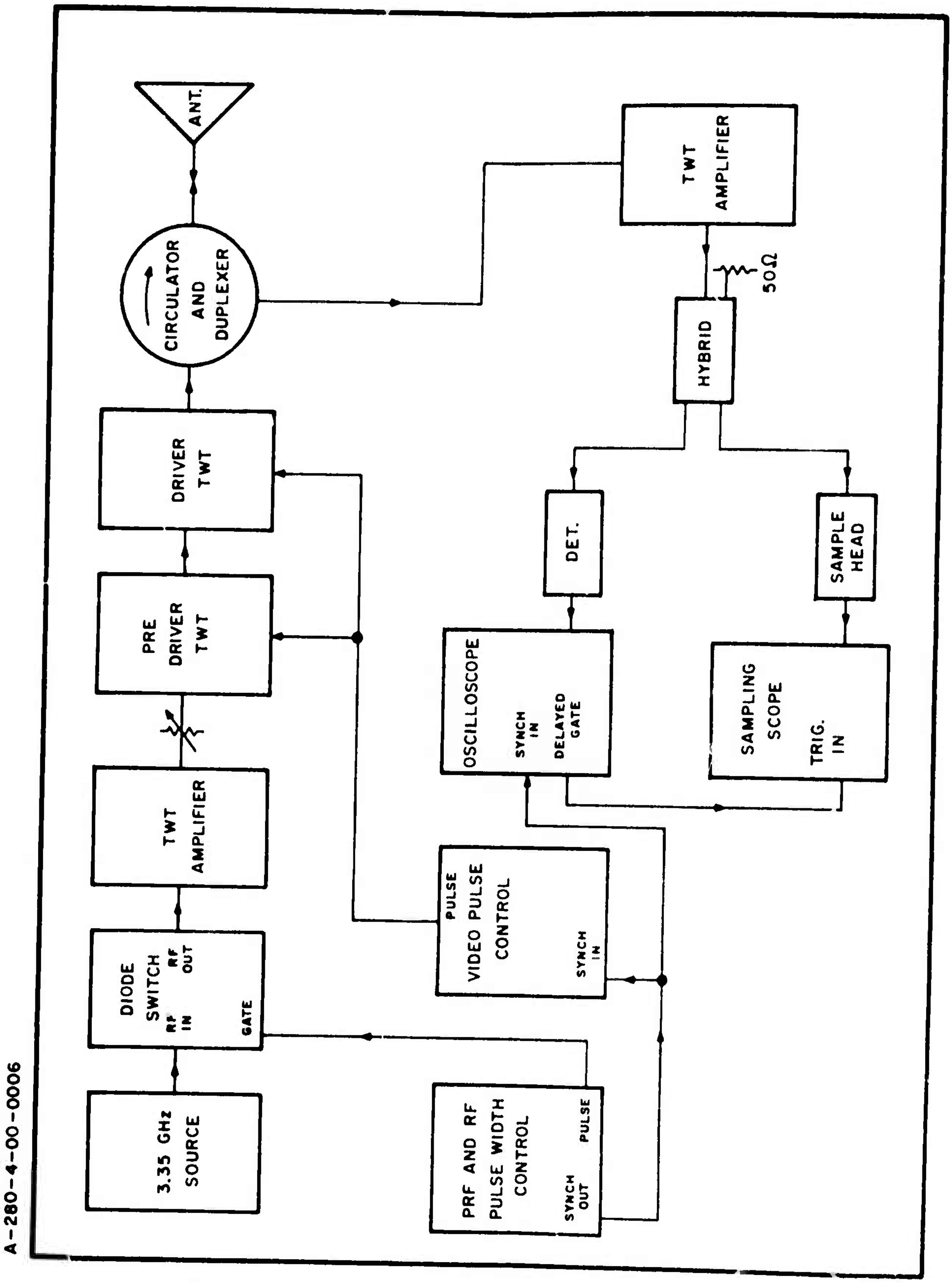


FIG. 6 BLOCK DIAGRAM OF CLUTTER TEST RADAR

V. REFERENCES

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VI. APPENDIX

A. COMPUTER STUDY

This report describes research performed at Riverside Research Institute and was prepared by E. Weitzman and T. Grish with contributions from D. Hancock. The assistance of staff members of Syracuse University Research Center and Massachusetts Institute of Technology/Lincoln Laboratory is gratefully acknowledged.

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COMPUTER UPGRADING FOR THE RADC WIDE-BAND PULSE COMPRESSION RADAR

I. INTRODUCTION AND BACKGROUND

This report presents results of a study undertaken by RRI for ARPA and RADC to aid in the selection of a computer for the upgraded Wide-Band Pulse Compression Radar located at the RADC Floyd Test Annex near Rome, New York. This radar is a very high bandwidth, high peak power, S-Band radar used for space object surveillance and identification (SOSI). The upgrading program was initiated early in 1973 to bring the radar from an experimental to a more clearly operational status having all of its original design capabilities fully realized. All of the major subsystems, such as the transmitter, receiver, synchronizer etc., were subjected to extensive measurements to assess performance, and where necessary equipment upgrading was undertaken. Early in the upgrading program it was realized that the existing on-site computer, a Digital Equipment Corporation PDP-1, could not support the functions required of an operational radar system. This study of the required computer capability was initiated as part of the general upgrading program with the objective of selecting a computer compatible with an operational environment for eventual installation at the facility.

In the computer study the first step was to determine all the required, as well as the desired, computer functions regardless of any particular computer configuration or of cost considerations. Sets of appropriate computer functions were then combined to form three options of varying operational complexity. Next, a number of computers and their characteristics were exam-

ined to allow matching of computers to the functions associated with each option. Finally, the costs of equipment purchase or lease, programming, interface design and construction were compiled and estimated for each of the computers in each of the options. No estimates were made of requirements for real-time radar-imaging; however, the growth potential of computer configurations were examined for this capability. After a brief description of the existing equipment and its limitations, the details of this study are presented in the remainder of the report.

II. EXISTING EQUIPMENT AND ITS LIMITATIONS

The existing equipment consists of a Digital Equipment Corporation PDP-1 computer. Its primary and almost sole function within the present (experimental) operating environment is to provide acquisition and pointing data to the radar. For this purpose precomputed satellite look-angle predictions are read by the PDP-1 from a tape, matched against a real-time clock, and output as pointing signals to the antenna servo at the appropriate time. Because of the PDP-1's limited memory size (4K) the look-angle predictions are computed on a machine at the Griffiss AFB. Experience has shown that the generation of look-angle predictions from NORAD or SPADATS-supplied orbital elements is a lengthy process requiring 1 to 2 days. This relatively poor turn-around time is entirely incompatible with a near operational radar.

In an operational environment, the need for extensive, sophisticated, and rapid radar checkouts and calibrations, as well as the capability for on-site diagnostic data reduction to assure data quality on a routine basis, demand the use of a substan-

tially more sophisticated computer. The present PDP-1 with its 4K words of memory and its limited language capability is not suitable. Inquiries have shown that since the PDP-1 is an old model, additional memory core and peripheral devices are no longer readily available and DEC no longer provides extensive support of the PDP-1 systems hardware and software. Even if additions could be made, the price of such additions would exceed that of a 3rd-generation mini-computer with a much improved capability over the PDP-1.

The Data Handling Equipment (DHE) presently employed for data collection at the Floyd radar is a stand-alone system utilizing a high-speed buffer memory and 2 16-track AMPEX instrumentation tape recorders. However, no extensive data diagnostics can be performed with the PDP-1, since playback of recorded data into the computer requires excessive time due, in part, to the core limitations. As part of the study, the possible use of the new site computer for the collection of the wide-band data was also considered. Furthermore, with a 3rd-generation computer, the capability exists to perform extensive post-mission analysis and diagnosis of data, thus assuring high quality data and rapid corrections of any radar malfunctions.

III. COMPUTER FUNCTIONS AND OPTIONS OF COMPLEXITY

Three options for upgrading the Floyd Site Computer were considered, each representing a different level of operational complexity. An attempt was made to match the functional requirements to the particular option considered. Thus, for example, the first option is the most ambitious and complex, from a functional as well as from an operational standpoint. This option would be chosen if the Floyd Radar is to go on a truly routine operational

basis with rapid data turn-around. The least ambitious option consists of a minimum of upgrading and would be required if the site were to remain in its present operational status. It would, however, result in higher quality data than is presently available. Finally, an option which envisions an environment somewhere between these two extremes was also considered.

The functions to be carried out under the first option are described fully. The second and third option are then treated in less detail since reference to the descriptions of the selected functions from the first option can be made.

A. OPTION 1

As mentioned previously, Option 1 should be considered if the Floyd Site Radar is to attain a near-operational status. Under these conditions, it is assumed that from 5 to 10 satellites will be tracked on a weekly basis. Short countdown and set-up times are also desired to respond rapidly to Air Force requests for tracking and identifying satellites immediately after launch.

A summary of the computer functions envisioned for Option 1 is shown in Table III-A-1. The following paragraphs describe these functions. Details of the actual computer implementation, i.e., the programs, core size and, where applicable, the execution time, are discussed in Section V and in Appendix A.

1. Pre-mission Preparation

Selection of the appropriate orbital elements from a satellite catalog or other source must be performed prior to the generation of radar pointing information for use during real-time tracking. The catalog consists of a list of space objects which are tracked routinely by Aerospace Defense Command (ADC) or other agencies. Prior to a tracking mission by the Floyd Site, orbital elements must be selected from this catalog based

TABLE III-A-1

COMPUTER FUNCTIONS (OPTION 1)

(TO BE CONSIDERED FOR A NEAR OPERATIONAL SYSTEM)

A. PRE-MISSION

1. Sort satellite ephemerides.
2. Compute and generate tables of pointing data for 5 to 10 satellites.

B. RADAR CALIBRATION AND CHECKOUT

1. Amplitude calibration for system linearity check for 45 MHz, 950 MHz and 3350 MHz loops - also control of frequency synthesizer for check over total range window.
2. Phase calibration - same as above.
3. High speed buffer checkout routine.
4. A/D checkout routine.
5. Pulse shape comparison to ideal or nominal.
6. Angle encoder check.
7. Monopulse check.
8. T/R recovery check.

C. REAL TIME

1. Acquisition - table look-up with manual initiation and scan.
2. Range Track - Helm's or other polynomial; centroid track (100 samples), lead and trailing edge track options; computed every PRI.
3. Angle Track - Helm's or other polynomial fit, 1 sample each in sum ΔAz and ΔEL, initial period of monopulse track,
4. Reacquisition and Computer Pointing - ephemeris update from portion of solid track. Prediction good for 10 min,
5. Radar Control - Direct computer interface with synchronizer, also control of tracking modes based on S/N criteria.
6. Data Recording - All W/B data samples, Time, Range and Angle information into computer core and out onto computer compatible tape.
7. Alpha Numeric Displays - R,A,E, status of track, etc.

D. POST-MISSION ON-SITE DIAGNOSTIC DATA REDUCTION

1. Track performance assessment - plots of R,A, and E residuals.
2. N/B and W/B RCS - may detect dropped bits, also compare to known history.
3. Compute MDS from noise samples.
4. Compute R-R periodograms (limited no.) - perio's are sensitive indicators of system performance.
5. Generate W/B digital RTI's.
6. Generate clean, calibrated data tapes.
7. Based on complete pass compute updated orbital elements for use in possible subsequent passes.

on such factors as the satellite's time of passage near the radar, the coarse pointing angles predicted, and whether the satellite observation is suitable in terms of expected radar cross section, attitude, tumbling rates or other factors.

Following the selection of the satellite, pointing angles as a function of time will be generated from the satellite's orbital elements. These angles will be utilized during actual track for acquisition purposes.

In an operational environment, the satellite catalog will require daily updating. The new information will be supplied by ADC, NORAD or other agencies and will consist of revised orbital elements for "old" objects or information for newly launched satellites.

The question of selecting the satellite to be tracked with the aid of the computer has not been addressed in this study. Such computer catalog maintenance would require added computer resources and more initial programming costs.

2. Radar Calibration and Checkout

The main purpose of calibrating and checking the radar is to assure the collection of meaningful and high quality data. To accomplish this purpose, a number of the radar's subsystems must be checked and set-up individually to establish their operating conditions, dynamic response, dynamic range, etc. Once the individual subsystems are prepared for the particular tracking mission, the complete radar system will be calibrated. The most important quantities which must be calibrated are the signal amplitude, signal phase, and the metrics, i.e., range, azimuth, and elevation angles. Procedures envisioned for checkout and calibration of the most important subsystems are outlined in the following.

The signal processing system must be checked completely at all stages. This will involve the injection of test target signals into the 45-MHz pulse compression system, the 950-MHz IF, and the 3550-MHz RF. Provisions for injection of the test signals are presently being implemented. During checkout, the test target pulse shape will be compared by the computer to the idealized or nominal response. If necessary, adjustments will be made (e.g., setting mixer local oscillator levels) to correct any discrepancies. Adjustments of transversal equalizers will be carried out during these checks to minimize time sidelobe levels. Finally, linearity checks and establishment of dynamic range limits at all three signal frequencies will also be performed by the computer during this checkout phase, by the generation of curves of injected signal strength vs output pulse amplitude. Similarly, the phase response will be checked by plotting injected signal phase vs phase detector output voltage. It is expected that the amplitude and phase tests will be carried out with the signal at a number of range bins within the range window, in order to establish performance linearity across the whole window. For this purpose, the computer will control the recently acquired frequency synthesizer to position the test target in the desired range bin.

The data collection system status will be established by tests of the analog-digital converters, the high-speed buffer memory, and the data recording computer routines. A computer algorithm for inserting pseudo-random data into the A/D's and the high-speed buffer and comparing it to the collected test data will accomplish this diagnostic function. (Such a routine has been used routinely and successfully at AMFAD.)

As part of the general checkout, the monopulse tracking receiver will also undergo various diagnostic tests. Until a suitable external boresight target is established, internal tests

will be executed. Thus, for example, angle error signals can be injected into the monopulse receiver, and the computer can calculate the departure from the expected antenna position. In addition, the transient response can be examined to set gains for optimum servo system and angle-track receiver performance. Furthermore, while driving the antenna along a simulated satellite orbit, the computer will check for such errors in the angle encoders as dropped bits and incorrect sequencing of bits.

A number of other pre-mission checks, of lesser complexity than those described, will also be implemented. These could include a T/R tube recovery-time check, and a range tracking performance test.

3. Real-Time Functions

Four basic functions will need to be performed by the computer in real-time during a satellite track. These are 1) target acquisition and pointing, 2) range and angle tracking, 3) control of signal bandwidth modes, and 4) recording of signature and metric data. The following paragraph describes the sequence of events envisioned for radar operation.

Pre-computed pointing information is output by the computer to the radar. A computer-generated raster or spiral scan around the nominal look-angles will be initiated by the operator, should acquisition not be achieved within, let us say, the first 30 sec. Upon acquisition, the computer will auto-track the target in range and angle. During this initial track, alternate transmissions of wideband and narrowband signals will be utilized to allow monopulse tracking, while at the same time stepping from narrowband mode to successively wider band mode operation and thus enabling wide-band range tracking. After approximately 30 to 60 sec in the interlace monopulse mode just described, the computer will be commanded to compute an updated

ephemeris based on the initial data span. Following this, predictions based on the updated ephermis will be issued by the computer for antenna pointing, and the radar will operate in the wide-band mode on all transmissions until loss-of-track. Data recording will be initiated as soon as this operating mode is achieved.

The most demanding requirements placed on the computer during real-time operation stem from the range tracking algorithms. It is envisioned that a procedure similar to the one in use at ALCOR will be implemented. The range error will be determined from 100 amplitude samples uniformly spaced over the range window. (It may be possible to utilize 200 samples, depending on the final choice of computer.) The computation of the centroid of the 100 range samples will require a large portion of the pulse repetition interval (PRI). The errors in centroid positions so computed over several PRI's will be subjected to a smoothing algorithm, such as a Helm's polynomial, for predicting the position of the range gate and sample timing in subsequent OPI's. Various options must be included in the range tracking algorithms to allow for all signal bandwidth modes as well as leading edge and trailing edge tracking.

The angle tracking algorithm is a much simplified version of the range tracking algorithm, since only a single sample of azimuth, elevation, and the sum monopulse signal is required for error determination in each PRI. Again a Helm's polynomial will be utilized for smoothing and prediction.

The computation of an updated ephermis, while possibly requiring a good deal of core memory, can be accomplished over several PRI's without serious consequences to the radar operation. Once a stable track is established in the final phases of satellite acquisition, the state vectors at a given time, i.e., range,

range-rate, azimuth, azimuth-rate, elevation, and elevation-rate, will be converted to orbital elements from which future pointing information will be computed.

It is envisioned that the data will be recorded via the computer directly onto computer-compatible tape. This alleviates the necessity for extensive reformatting from PCM tapes. The average data rate, based on 400 8-bit amplitude and 8-bit phase samples in 2 polarizations per PRI, is close to 120 Kbytes per second. Computer tape recorders capable of handling such rates are available. The 400 samples in each PRI are collected at a rate of 10 MHz. Because of this high sampling rate, intermediate high-speed buffer storage is required prior to entry into the much slower computer memory. For this purpose the presently existing high-speed buffer will be adapted for operation with the particular computer selected. In the computer memory, two storage areas will be allocated which will alternately accept data from the radar (via the direct memory access bus) or output data to the tape recorder. Such an arrangement has been established to operate reliably in other radars; for example, AMRAD has this type of double buffering scheme.

4. Post-Mission On-Site Data Reduction

The reformatting, calibration, and initial examination of the data will be performed at the radar facility. This will ensure that all operating conditions and/or anomalies either will be taken into account during calibration or at least appropriate flags, indicating poor or unusable data, will be provided along with the data to the data recipients. This procedure will also assure that malfunctions are discovered rapidly by radar personnel, presumably leading to remedial action in the shortest time possible.

Some of the diagnostics which are presently considered necessary are:

- The plotting of range, azimuth, and elevation residuals (differences between raw and smoothed data) for radar track assessment and range counter and angle encoder checks.

- The plotting of radar cross-section data, both wideband and narrowband, to determine if any amplitude A/D bits malfunctioned.

- The plotting of minimum-detectable signal to verify system noise performance, and the computation of selected range, range-rate periodograms to check if any phase A/D bits malfunctioned.

- The generation of a digital RTI to aid in the selection of post-mission analysis and imaging. Such an RTI is invaluable in determing the position and lifetime of individual scattering centers. The "clean" calibrated data tapes will be generated from data intervals which, upon initial examination, show promise of successful imaging. The pre-mission calibration tables will be utilized to convert the recorded A/D counts into amplitude and phase units (i.e., volts or watts, and degrees, revolutions or radians, respectively). A final task during the post-mission processing will be to generate an updated ephemeris based on the data from the complete satellite pass. The program for this is expected to require a substantial amount of core since it should be based on a fairly sophisticated mathematical model of orbit mechanics.

B. OPTION 2

If it is decided that the Floyd radar is to be operated in a less ambitious manner than outlined under Option 1, i.e., remain in an experimental status but with extended capabilities over the presently existing ones, the computer functions of

Option 2 would be indicated. The mission support level would be to track from 2 to 5 satellites per week, with data from only a few of those missions being reduced. It is assumed that in such an environment more time between missions would be available, hence more checks and diagnostics could be carried out manually.

Table III-B-1 summarizes the functions planned for this option. (For a detailed description, refer to Section III-A.) The major differences between these functions and those outlined under Option 1 concern pre- and post-mission checks and diagnostics, the sophistication of the range-tracking algorithm, and the data recording. The reduction in these capabilities compared to Option 1 results in less extensive computing requirements.

The selection of satellite ephemerides and computation of pointing information will still be carried out as under Option 1. Less extensive and fewer pre-mission calibrations and checks would be performed by the computer. In particular, linearity checks and calibration over all range bins within the total range window will no longer be carried out. During real-time satellite track, range tracking utilizing only 10 to 20 samples will be performed. This, then, is not a true centroid track and may lead to rougher tracking. Data recording would be carried out with the presently existing equipment; however, sufficient modification would be incorporated to allow post-mission playback and reformatting in a reasonable amount of time. Finally, the post-mission checks and diagnostics would consist only of track assessments, checking for dropped amplitude A/D bits, and checks of system noise performance. Clean, calibrated data tapes would still be produced.

C. OPTION 3

The least ambitious computer upgrading program is outlined in this section. Option 3 would be chosen if the Floyd radar is to continue operating in a manner similar to its recent past.

TABLE III-B-1

COMPUTER FUNCTIONS (OPTION 2)

(TO BE CONSIDERED FOR A MORE EXPERIMENTAL SYSTEM THAN THAT OF OPTION 1

A. PRE-MISSION

1. Sort satellite ephemerides.
2. Compute and generate tables of pointing data for up to 5 satellites.

B. RADAR CALIBRATION AND CHECKOUT

1. Amplitude calibration for system linearity check for 45 MHz, 950 MHz and 3350 MHz loops at center of range window only.
2. Phase calibration - same as above.
3. Pulse shape comparison to ideal or nominal.

C. REAL TIME

1. Acquisition - table look up with manual initiation and scan.
2. Range Track - Centroid track over 10-20 central samples, lead edge and trailing edge track options.
3. Angle Track - interlace monopulse throughout pass.
4. Radar Control - Direct computer interface with synchronizer, also control of tracking modes based on S/N criteria.
5. Data Recording - Present capability with augmentation for fast playback into the computer.

D. POST-MISSION ON-SITE DIAGNOSTIC DATA REDUCTION

1. Track performance assessment - plots of R, A, and E residuals.
2. N/B and W/B RCS - may detect dropped bits, also compare to known history.
3. Compute MDS from noise samples.
4. Generate clean, calibrated data tapes.

Only one to two missions would be supported per week. It is felt, however, that even under these circumstances it is desirable to upgrade the present computer capability simply to improve the data quality.

A summary of the computer functions for Option 3 is compiled in Table III-C-1. Under this option (1) no on-site selection of satellite ephemerides and pre-computation of pointing information would be carried out, (2) no computer range and angle tracking would be implemented, and (3) present data recording would be retained, augmented by fast playback (as described under Option 2). The post-mission functions would be identical to those in Option 2.

D. PROGRAMMING STAFF REQUIREMENTS

An estimate of the amount of programming time required to implement each of the three options just described is presented in Table III-D-1. These requirements are basically independent of actual choice of computers because (1) FORTRAN (in which many of the programs will be written) is relatively well standardized, and (2) all the candidate computers have an assembly language so that the development of non-FORTRAN programs should take similar amounts of time on the various computers.

IV. INTERFACE REQUIREMENTS

The computer will be utilized to provide commands to the radar, carry out various real-time computations during a tracking mission as well as during radar check-out, and, (in Option 1) to collect data. Interface hardware will be built to route commands and data from the radar to the computer and vice-versa. To summarize briefly, for Option 1, the interface equipment will:

TABLE III-C-1

COMPUTER FUNCTIONS (OPTION 3)

(TO BE CONSIDERED FOR MINIMAL UPGRADING)

A. PRE-MISSION

Done off-site.

B. RADAR CALIBRATION AND CHECKOUT

1. Amplitude calibration for systems linearity check for 45 MHz, 950 MHz and 3350 MHz loops at center of range window only.
2. Phase calibration - same as above.
3. Pulse shape comparison to ideal or nominal.

C. REAL TIME

1. Acquisition - present capability.
2. Range Track - upgrade present hardware tracker.
3. Angle Track - interlace monopulse.
4. Radar Timing and Control - present capability.
5. Data Recording - present capability with augmentation for fast playback into computer.

D. POST-MISSION ON-SITE DIAGNOSTIC DATA REDUCTION

1. Track performance assessment - plots of R,A, and E residuals.
2. N/B and W/B RCS - may detect dropped bits, also compare to known history.
3. Compute MDS from noise samples.
4. Generate clean, calibrated data tapes.

TABLE III-D-1

PROGRAMMING ESTIMATES

(Entries are in man-months of professional effort)

OPTION	TASKS				
	Pre-Mission	Radar Calibration and Check-Out	Real-Time	Post-Mission On-Site Diagnostic Data Reduction	Total
1	1	6	15	8	30
2	1	4	7	4	16
3	N/A	4	2	4	10

1. Route antenna pointing information from the radar to the computer and pointing commands from the computer to the radar. Commands will be based on computed satellite ephemeris or tracking errors, depending on mode of operation.

2. Route the computer commands of a new, predicted range sample position to the radar following computations based on amplitude samples from previous PRI's.

3. Temporarily store collected amplitude samples and feed them to the computer for data recording.

4. Route operator angle and range-tracking commands from the radar to the computer. Route signal mode commands, status displays, and alphanumeric information from the computer to the radar.

5. Permit manual selection of the various radar functions, such as:

a. Testing signal processing equipment through three test loops.

b. Selecting the required ephemeris for acquisition.

c. Initiating check-out tests.

d. Tracking in centroid, lead-edge, or trailing-edge modes.

6. Route commands from the computer to the radar, and data from the radar to the computer for check-out and/or calibration of:

a. A/D Converters.

b. Pulse compression equipment.

c. Signal processing equipment through three test loops.

d. Monopulse receiver and angle encoders.

e. TR recovery time.

f. Transversal equalizers (pulse-shape comparison to nominal or ideal).

The above list is not exhaustive but is representative of the functions contemplated. It is clear that complex interface equipment will be required. A more complete listing of the radar signals and computer commands that would be needed for Option 1 is included in Appendix B. The interface requirements in terms of actual equipment, equipment cost, and staff is provided in Table IV-1. It is in this table that the interface requirements for the two less ambitious options are appropriately reduced.

V. COMPUTER SELECTION

A. INITIAL SELECTION

The number of computers to choose from is vast, especially when mini-computers are under consideration. To limit the choice, a summary survey in the Auerbach Standard EDP Reports[1] was consulted It described word size, maximum core, cycle time, instruction timing, and other general specifications. In addition, information was obtained from computer company representatives at the American Federation of Information Processing Societies National Computer Exhibition. When the field was narrowed, more detailed information in the Auerbach Reports and in manufacturers' literature was studied.

Initially, a number of computers were chosen and attempts were made to determine whether they were reasonable candidates to perform the required functions. At this point, whether they

[1] See Sec. VIII for numbered footnotes.

TABLE IV-1

SPECIAL INTERFACE REQUIREMENTS

Option	Function	Equipment	Cost of Equipment	Labor Requirements
1				Professionsl - 15 mm Support - 12 mm
	System control and display interface	(a) 1 system (man-to-computer) control register with control logic and cabling.	$ 4,000	
		(b) 6 display registers with control logic and cabling.	$ 1,400	
		(c) 4 computer-to-radar control registers (including range tracker and angle tracker interface) with control logic and cabling.	$11,000	
		(d) 2 buffer registers with control logic and cabling.	$ 8,000	
	Data Acquisition and Recording	Use of existing A/D converters, high speed buffer memory, and A/D sample generator is assumed. A Direct Memory Access (DMA) is required in the computers configuration. Interface between high speed buffer and DMA with control logic and cabling.	$ 6,000	
		Total	$30,400	
2				Professional - 6 mm Support - 4 mm
	Operating control and system status	Buffer register with control logic and cabling.	$ 4,000	
	Computer Range Tracker	Range register with control logic and cabling.	$ 8,000	
	Fast playback into computer of Data Handling Equipment recorded data.	Interface between high speed buffer in DHE: Shift register with contol logic and cabling.	$10,000	
		Total	$22,000	
3				Professional - 4 mm Support - 2 mm
	Operating control and system interface	Buffer register with control logic and cabling.	$ 4,000	
	Fast playback into computer of Data	Interface between high speed buffer in DHE: Shift register with control logic and cabling.	$10,000	
		Total	$14,000	

could also be useful for the various options was not considered. For the real-time functions, operation time was the most important factor. Section VII describes the analysis that was performed in order to estimate the various real-time functions. For non-real-time functions core size was the overriding factor. Core requirements were estimated from existing computer programs performing similar tasks.

Consideration shown in Tables V-A-1 and V-A-2, which define the capabilities of the computers with respect to the required functions, enabled the choice of computers to be narrowed.

The IBM-360-30 was eliminated because it was too small for even the simplest options. The Data General Supernova, Control Data Corporation CDC-1714, and the Honeywell Information System HIS-200-1015 were removed from consideration because their speed, size restrictions, lack of expandability, or cost made them less attractive than the remaining five computers which became serious candidates: Digital Equipment Corporation PDP-11/45, Data Craft DC 6024/1, Xerox Data Systems Sigma 5 and Sigma 3, and the IBM-370-135. These tables were studied to determine which computer systems could be utilized for the various options. For the non-real-time functions, required core size was compared to the maximum core size of each machine. Timing considerations for the real-time functions were driven, in Options 1 and 2, by the speed with which the computer could perform the range tracking. However, care was taken to ensure that the chosen computers would be able to perform not only the range tracking but all the real-time functions required within a PRI (14.2 ms) with some reasonable amount of time left for real-time functions that would also have to be performed over a number of PRI's.

TABLE V-A-1

FUNCTIONS AND COMPUTER CAPABILITIES

Radar Function	Core Required*	XDS Sigma 3	DEC PDP-11/45	Data General Supernova	CDC 1714	Data Craft DC-6024/1	HIS 200-1015	XDS Sigma 5	CDC 3174-2	IBM 360-30	IBM 370-135
1. Acquisition and Pointing											
a. Table Look-Up	750 words	2 ms	.25 ms	6.8 ms	3.9 ms	.15 ms	2.6 ms	.15 ms	.18 ms	6.6 ms	1.5 ms
b. Orbital Update Based on Radar Data											
i. Second Order Least Squares Fit	500 words	10.6 ms	1.3 ms	Too Slow	Too Slow	.76 ms	10.2 ms	.73 ms	1.8 ms	Too Slow	3.1 ms
ii. Simple Kalman Filter Time for 1 sec update. Too slow if it takes more than 1 sec.	3K words	519 ms	47 ms	Too Slow	773 ms	30 ms	113 ms	35 ms	79 ms	Too Slow	149 ms
iii. Conversion between Radar Coorinates and Orbital Elements	1½K words	Requires more than one pri for any machine.									
c. Scans	800 words	6.5 ms	.85 ms	23 ms	13 ms	.5 ms	8.7 ms	.5 ms	.6 ms	22 ms	5 ms
2. Computer Range Track a. Alcor Scheme With 100 track samples	1800 words	Too Slow	4.3 ms	Too Slow	Too Slow	2.4 ms	Too Slow	2.1 ms	5.2 ms	Too Slow	6.8 ms
With 200 track samples		Too Slow	8.1 ms	Too Slow	Too Slow	4.4 ms	Too Slow	3.9 ms	10.0 ms	Too Slow	12.3 ms
b. Rampart Scheme With 100 track samples	1450 words	Too Slow	7.2 ms	Too Slow	Too Slow	4.4 ms	Too Slow	4.1 ms	9.7 ms	Too Slow	9.9 ms
With 200 track samples		Too Slow	Too Slow	Too Slow	Too Slow	8.1 ms	Too Slow	8 ms	Too Slow	Too Slow	Too Slow
3. Computer Angle Track	500 words	10.2 ms	1.3 ms	Too Slow	Too Slow	.79 ms	10.7 ms	.93 ms	2.3 ms	Too Slow	3.1 ms

* Based on a 32-bit/word computer.

TABLE V-A-2

POST MISSION FUNCTIONS AND COMPUTER CAPABILITIES

Function	Core Required	XDS Sigma 3	DEC PDP-11/45	Data General Supernova	CDC 1714	Data Craft DC-6024/1	HIS 200-1015	XDS Sigma 5	CDC 3174-2	IBM 360-30	IBM 370-135
		COMPUTER AND LARGEST CORE SIZE									
	Words	65K wds 16bits/char	128K wds 16bits/wd	32K wds 16bits/wd	65K wds 16bits/wd	65K wds 24bits/wd	131K char 6bits/wd	131K wds 32bits/wd	42K wds 24bits/wd	16K wds 32bits/wd	61K wds 32bits/wd
1. Plots of Range, Azimuth, and Elevation Residuals	16K	OK	OK	OK	OK	OK	OK	OK	OK	No Good	OK
2. RCS	15K	OK	OK	OK	OK	OK	OK	OK	OK	No Good	OK
3. MDS	5K	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
4. Periodograms (64 frequency bins)	22K	OK	OK	No Good	OK	OK	No Good	OK	OK	No Good	OK
5. Digital RTI's	5K	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
6. Generate Clean, Calibrated Data Tapes	16K	OK	OK	OK	OK	OK	OK	OK	OK	No Good	OK
7. Update Orbit to Subsequent Passes Based on Data From One Complete Pass (estimated from AEROSPACE's FIT Program)	29-44K	OK	OK	No Good	OK	OK	No Good	OK	OK	No Good	OK

Note: The above estimates were based on similar programs utilized by RRI in other projects.

B. OPTIONS AND ASSOCIATED COMPUTERS

1. Generalized Configuration

Generalized computer configurations were defined for each option assuming that the algorithms were operating with a 32-bit machine. Memory requirements of the 16- and 24-bit word computers were increased by 50% over that of the 32-bit word computers in order to cover the additional words required for single and double precision floating point variables.

It is impossible for the actual computer systems to contain the same components, for each computer manufacturer has slightly different types of equipment and sells or leases the equipment in different quantities. A system closest to the generalized configuration was always chosen unless it was more economical for a particular machine to be better equipped than required. In Options 2 and 3, two configurations were generated, the first containing no disc storage, the other containing some disc storage but less core memory storage than the first. The less expensive of the two was used in the final computer vs cost table (Table VI-A-1).

All the computers have a central processor with floating point hardware, memory protect, power fail-safe, and interrupts, an operator console, a slow card reader (nominally 300 cards per minute), a slow line printer (nominally 300 lines per minute) and a basic set of I/O channels required for the peripherals and for the functions of the simplest option.

2. Option 1 Configuration

In addition to the basic computer requirements, computers able to operate under Option 1 would include: 44K words of memory, a disc pack unit, a direct memory access (DMA), and the equivalent of two high speed (120K char/sec) 9-track tape units with separate controllers. The actual Floyd radar data rate

would be approximately 120K char/sec. However, it is not advisable to assume that the tape recorders would always operate at their quoted speeds. With two separate controllers, the first recording one polarization on one tape unit, and the second recording the other polarization on the other tape unit, a high recording rate is assured.

3. Option 2 Configuration

Similarly, Option 2 computer configurations would augment the basic system with: (1) 12K words of memory and some disc, or 20K words of memory and no disc, and (2) 2 9-track, slow speed (30-40K char/sec), tape units with one controller.

4. Option 3 Configuration

Option 3 computers would augment the basic system by: (1) 8K words of memory and some disc, or 16K words of memory and no disc, and (2) 2 9-track, slow speed (30-40K char/sec), tape units with one controller.

For each of the three options, Table V-B-1 outlines the computer configurations of the candidate computers.

5. Computer Configuration Cost Estimates

The details of the configurations and cost for each of the computers that were considered possible choices are contained in Appendix C, Section VII. The equipment common to each option was costed as a package and included in the price of each option. A summary of the costs of all the computers is provided in Sec. VI

The prices determined for the computer systems were based on figures in the Auerbach Standard EDP Reports and do not include GSA reductions. In addition, sales representatives of IBM, Digital Equipment Corporation, and Data Craft provided approximate costs for various pieces of equipment. The current Xerox Data System price list was also utilized. It should be

TABLE V-B-1

COMPUTER REQUIREMENTS

OPTIONS	CANDIDATE COMPUTERS	
Option 1	DEC-PDP-11/45	16 bits/word; 64K memory 1.2 mb disc pack; 1 - 9T-60K char/sec tape unit 1 - 9T 240K char/sec tape unit
	DC 6024/1	24 bits/word; 64K memory 7 mb disc pack 2 9T 120K char/sec tape units
	XDS Σ5	32 bits/word; 48K memory 24 mb disc pack 2 9T 120K char/sec tape units
	IBM-370-135	32 bits/word; 49K memory 90 mb disc pack 1 9T 320K char/sec tape unit 1 9T 50K char/sec tape unit
	Each computer has a full word channel of Direct Memory Access. Each tape unit has a separate controller.	
Option 2	DEC-PDP-11/45	16 bits/word; 16K memory 1.2 mb disc pack
	DC 6024/1	24 bits/word; 16K memory 7 mb disc pack
	XDS Σ5	32 bits/word; 32K memory
	IBM-370-135	32 bits/word; 24K memory
	Each computer has two 9T slow (30 - 40K char/sec) tape units.	
Option 3	DEC-PDP-11/45 XDS Σ3	16 bits/word; 24K memory
	DC 6024/1	24 bits/word; 24K memory
	XDS Σ5	32 bits/word; 16K memory
	Each computer has two 9T slow (30 - 40K char/sec) tape units.	

Note: All computer configurations would have floating point hardware, a slow card reader, a slow line printer, an operator's console, interrupts, power fail safe, memory protect, and enough I/O channels for the option under which it is being considered.

noted that the costs mentioned here could probably be reduced during actual negotiations with the particular computer company. It should also be pointed out that maintenance costs and computer site preparation costs were not considered. The former is proportional to the cost of the computer system; the latter is a nearly fixed cost, independent of any particular system.

VI. CONCLUSIONS

A. SUMMARY

Table VI-A-1 summarizes the cost of improving the WPCR on-site computing capability for each of the three options that have been defined. Note that where the cost of a yearly lease is not listed, it is because the computer manufacturer does not lease its computers. The programming and hardware interface work costs are based on current average rates for Riverside Research Institute programmers, engineers, and support staff and include an allowance for overhead and fee. For each option, the growth potential column refers to the feasibility of expanding the computer configuration to that of the next higher option.

In view of Syracuse University Research Center's (SURC) investigation of the possibility of real-time radar imaging at the radar site, the growth potential column for Option 1 indicates the feasibility of expanding the computers to configurations which would be able to perform real-time radar imaging. Table VI-A-2 indicates the equipment and cost that would be necessary in order to implement this additional function. It is included merely to provide an estimate of the added costs for this function (Man-power costs and the cost of possible graphical display equipment are not included.) and to show which computers would remain possible choices if real-time imaging were to be implemented.

TABLE VI-A-1

ESTIMATED COST OF WPC RADAR COMPUTER UPGRADING

OPTIONS	COMPUTERS	PURCHASE PRICE	YEARLY[1] LEASE	INTERFACE COSTS MATERIALS	INTERFACE COSTS LABOR[2]	PROGRAMMING[2] COSTS	TOTAL PURCHASE	TOTAL YEARLY LEASE (FIRST YEAR)	GROWTH POTENTIAL
1 Upgrade to a near operational system	DEC-PDP-11/45	185,000	N/A	43,000	102,000	116,000	446,000	N/A	Good
	XDS Σ5	426,000	155,000				687,000	416,000	Excellent
	DC 6024/1	296,000	N/A				557,000	N/A	Poor
	IBM-370-135	526,000	134,000				787,000	395,000	Poor
2 Upgrade to more experimental system	DEC-PDP-11/45	82,000	N/A	22,000	39,000	62,000	205,000	N/A	Excellent
	XDS Σ5	229,000	91,000				352,000	214,000	Excellent
	DC 6024/1	166,000	N/A				289,000	N/A	Excellent
	IBM-370-135	368,000	88,000				491,000	211,000	Excellent
3 Minimal upgrading	DEC-PDP-11/45	76,000	N/A	14,000	25,000	39,000	154,000	N/A	Excellent
	XDS Σ5	197,000	68,000				275,000	146,000	Excellent
	XDS Σ3	119,000	41,000				197,000	119,000	Poor
	DC 6024/1	160,000	N/A				238,000	N/A	Excellent

[1] Maintenance is included in the yearly lease figures.

[2] Based on a rate of: 5.0 K/mm for professionals,
3.9 K/mm for programmers, and
2.2 K/mm for support staff, including overhead, fees, etc.

TABLE VI-A-2

FLCYD RADAR SITE IMPROVEMENTS

RADAR IMAGING

OPTION	COMPUTER CONFIGURATION		INCREMENT IN PURCHASE COST OVER OPTION 1	INCREMENT IN YEARLY LEASE OVER OPTION 1
Radar Imaging	DEC-PDP-11/45	16 bits/word 64K memory over that of Option 1*	$96,000	N/A
	DC 6024/1	24 bits/word 84K memory over that of Option 1 Not Feasible - 65K maximum core, 145K required	N/A	N/A
	XDS Σ5	32 bits/word 56K memory over that of Option 1	$170,000	$41,000
	IBM-370-135	32 bits/word 56K memory over that of Option 1 Not Feasible - 61K maximum core, 97K required	N/A	N/A

* See Section VI-B.

B. RECOMMENDATIONS

The following recommendations are made. If it is decided to undertake a minimal upgrading of the WPCR radar (Option 3) to achieve higher quality data than is presently available while still retaining the present very limited operational status, the PDP-11/45 is suggested because of its speed, excellent growth potential (which would allow possible expansion at a later date to a more complex option), and low cost. For similar reasons, the PDP-11/45 is also recommended if a more substantial upgrading is to be carried out (Option 2).

If the radar is to go on a routine operational basis with rapid data turn-around (Option 1), the PDP-11/45 is still very attractive,particularly because of its low cost. However, the Xerox Data Systems Sigma 5 can easily expand into a computer capable of real-time radar imaging. Real-time radar imaging is possible on the PDP-11/45, but, since the maximum core available on PDP-11/45 is less than that required for efficient radar imaging, the number of images per satellite pass would not be as great as if this function were performed on the Sigma 5.* For that reason, if optimum real-time radar imaging is the current objective, or of future importance, the XDS Sigma 5 is recommended.

* The fact that the programs for radar imaging exist on a Sigma 5 would lower the programming cost and thus ameliorate the price difference between a PDP-11/45 and the Sigma 5.

VII. APPENDICES

APPENDIX A

REAL-TIME ALGORITHMS

This appendix describes the algorithms used to determine the required computer size and to time the execution speed for those real-time functions that are defined in Section III.

The computer (assembly language) instructions required for each algorithm were sorted into:

(1) floating point additions (ADD's)

(2) floating point multiplications or divisions (MULT's)

(3) a variety of control instructions such as loads, stores, compares, branches, shifts, and fixed point additions. All of the third are counted in the LOAD's.

1. Acquisition and Pointing

a. Table Look-Up

Initialization would consist of retrieving from auxiliary storage the table for the satellite to be tracked. The table would be 600 words long for a 10 minute pass, with one point/sec and ten words per point. Every prf, a table look-up and linear interpolation would be performed.

BASIC INSTRUCTIONS

Operation	No. per PRI
ADD	6
MULT	6
LOAD	15

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NUMBER OF LOCATIONS REQUIRED

Basic Instructions	27
Variables	600
Ancillary, initialization, instructions	123
	750

b. Orbital Update Based on Radar Data

A detailed description of this smoothing method, together with techniques for computer implementation, can be found in Appendix 2 of RRI Research Note N-29/070-4-30, "User's Guide To The Trajectory Program."[2]

(1) Second Order Least-Squares Fit On Range, Azimuth, and Elevation.

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	75
MULTI	40
LOAD	60

NUMBER OF LOCATIONS REQUIRED

Basic instructions	125
Ancillary, initialization, instructions	300
Constants	75
	500

(2) Simple Kalman Filter

Estimates for this algorithm were determined from the TRADEX real-time version which uses 8K of core on an XDS Sigma 5 (32 bits/word) computer, and requires 35 ms for a 1-second update. The floating point multiplication was used as an indicator of the general speed of the machine. The ratio of executic

time for the Sigma 5 multiplication to that required of each for the computers under consideration was used to extrapolate the time requirements.

(3) Converting Between Radar Coordinates and Orbital Elements in Order to Reacquire Within a Pass

This algorithm was taken from "Methods of Orbit Determination," by P. R. Escobal.[3] Both the first part, converting from radar coordinates to orbital elements, and the second part, moving along the orbit and returning to radar coordinates, can be performed over several PRI's. For all the computers under consideration the second part would definitely have to be performed over several PRI's, with the faster computers providing more rapid reacquisition. The core requirement would be approximately $1\frac{1}{2}$K words.

c. <u>Scans</u>

The requirements outlined here are based on the scan algorithm used at the AMRAD radar. Scan tables are prepared in advance, stored on disc, and used in a table look-up scheme in real-time. Many different scan patterns can be generated in this manner. Only 50 locations are required in addition to a table look-up subroutine. Altogether, 800 locations would be required. At AMRAD, each update of the radar position along the scan pattern requires 500 μsec. Timing requirements for other computers can be extrapolated from this by utilizing the relative timing of the radar acquisition and pointing table look-up scheme.

2. <u>Range Tracking</u>

The RAMPART schemes are described in L. R. Rice's memo on "RAMPART Range Tracking Software."[4] The ALCOR algorithms are from the "ALCOR Data User's Manual."[5] The highest core requirement is obtained utilizing the ALCOR centroid and lead edge schemes with Helm's smoothing or ALCOR recursive polynomial

smoothing techniques. The 1800 locations required include 800 locations for double buffering radar data, 256 for a calibration table, and 200 for a program controlling the entire range track computer procedure. The lowest core requirement (1450 words) includes these 1256 locations and is obtained with the RAMPART centroid, lead edge, and recursive predictor. For both RAMPART and ALCOR, the centroid scheme requires the most time.

a. Range Error Calculations

In the following tables, n is the number of range cells in the range gate. In Section V, timing requirements are calculated for n = 100 and n = 200.

(1) RAMPART Centroid Detection Scheme

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	1
MULT	n + 2
LOAD	5n + 4

Calculating the range error requires 16 instructions and 3 variable locations. Moreover, each signal requires calibration. Eight bits per signal require 2^8 (or 256) locations for a calibration table in a table look-up scheme. Thus a total of 275 locations are required.

(2) ALCOR Centroid Calculations

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	2n
MULT	2
LOAD	2n + 10

The number of locations required, including ancillary and initializing instructions, variables and constants. and calibration table is 500.

(3) RAMPART Lead Edge Detection

For the most time consuming algorithm,

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	n
MULT	-
LOAD	8n + 50

Total core requirements are 170 locations.

(4) ALCOR Lead Edge Detection

a. Coarse - similar to RAMPART Lead Edge

b. Vernier - similar to ALCOR wideband centroid scheme.

b. Range Smoothing Techniques

(1) RAMPART Digital Recursive Predictor Corrector

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	6
MULT	11
LOAD	15

Core requirements would be 70 locations.

(2) Helm's Smoothing

This scheme is for use with ALCOR Lead Edge Tracking.

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	6
MULT	10
LOAD	16

Core requirements would be 40 locations.

(3) ALCOR Lead Edge/Centroid Recursive Polynomial

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	10
MULT	15
LOAD	16

Core requirements would be 56 locations.

3. Angle Tracking

An angle tracking scheme, similar to that used at AMRAD would require calculating normalized ΔAz and ΔEl, performing Helm's smoothing on each, then scaling the smoothed differences for gain corrections, and outputting the error signals to D/A converters which would feed into the antenna servos.

BASIC INSTRUCTIONS

Operations	No. per PRI
ADD	26
MULT	36
LOAD	78

Core requirements are approximately $\frac{1}{2}$K words.

APPENDIX B

RADAR SIGNALS AND COMPUTER COMMANDS

(This appendix contains a list of radar signals and computer commands that would be needed for Option 1 (as defined in Sec. III))

SUMMARY OF REQUIRED DATA RATES

Radar Data from Radar to Computer	155 bits/per PRI
Signature data from Radar to Computer	12,800 bits/per PRI
Commands from Computer to Radar	371 bits/per PRI
Data Rate Radar to Computer (including parity bits)	1,020,207 bits/sec
Data Rate Computer to Radar (including parity bits)	26,390 bits/sec

Function		No. of Bits per PRI	Bits/Sec	ORIGIN (R = Radar, C = Computer)
Test Loop 1	Select	1	70	R
	Commands	6*	420	C
Test Loop 2	Select	1	70	R
	Commands	6*	420	C
Test Loop 3	Select	1	70	R
	Commands	6*	420	C
Ephemeris 1 Select		1	70	R
Ephemeris 2 Select		1	70	R
Ephemeris 3 Select		1	70	R
Phase Calibration Commands		8*	560	C
Pulse Shape Compute Select		1	70	R
A/D Test Select		1	70	R
A/D Test Commands		32*	2240	C
High-Speed Buffer Test Select		1	70	R
High-Speed Buffer Test Command		32*	2240	C

* Rough Estimates

RADAR SIGNALS AND COMPUTER COMMANDS (Cont'd)

Function	No. of Bits per PRI	Bits/Sec	ORIGIN R = Radar C = Computer
Az Encoder	18	1260	R
El Encoder	18	1260	R
Az Error	10	700	R
El Error	10	700	R
Sum Reference	8	560	R
Az Command	18*	1260	C
El Command	18*	1260	C
Monopulse Autotrack Select	1	70	C
Interface Monopulse Select	1	70	R
Az Command Display	16	1120	C
El Command Display	12	840	C
Az Rate Display	12	840	C
El Rate Display	12	840	C
Manual Az Input	8*	560	R
Manual El Input	8*	560	R
Az Stop Signal	2	140	R
El Stop Signal	2	140	R
Az Rate Limit	1	70	R
El Rate Limit	1	70	R
Scan Mode 1 Select	1	70	R
Scan Mode 2 Select	1	70	R

RADAR SIGNALS AND COMPUTER COMMANDS (Cont'd)

Function	No. of Bits per PRI	Bits/Sec	ORIGIN R = Radar C = Computer
Range Command Display	20	1400	C
Range Command	25	1750	C
Range Display	20	1400	C
Range Rate Display	12	840	C
Jump Range Select	1	70	R
Manual Jump Range	25	1750	R
Slew Range Select	1	70	R
Manual Slew Range	12	840	R
Auto Track Select	1	70	R
Signal Mode Command	8	560	C
Signal Mode Display	8	560	C
Manual Mode Select	8	560	R
Centroid Track Select	1	70	R
Lead Edge Track Select	1	70	R
Trailing Edge Track Select	1	70	R
Compute Ephemeris Select	1	70	R
Calibration Attenuater Commands	8*	560	C
Ephemeris Pointing Select	1	70	R
Ephemeris Ready Display	1	70	C
Time Display (GMT)	32	2240	C
Time to Track (Sec)	32	2240	C
Record Select	1	70	R
Data Samples (400 range bins, 2 polarizations amplitude phase)	12,800	896,000	R
Frequency Synthesizer Commands	32*	2240	C

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS

Data Craft DC-6024/1 (24 bpw)* No Rental Available

Basic Equipment	PURCHASE	EQUIPMENT
(Needed For All Options)	$ 53250	CPU - with 8K (24 bit) 600 nsec Cycle Time Memory, Clock, Interrupts, Memory Protect, ASR-33, Some I/O Channels
	18000	Scientific Arithmetic Unit
	4500	Card Reader (300 cpm)
	12500	Line Printer (300 lpm)
Total	$ 88250	

Option 1

	PURCHASE	EQUIPMENT
	$ 88250	Basic Equipment
	124500	56K Extra Core With Rack
	23000	7 mb Disc Pack and Controller
	57000	2 - 9T 120 Kc/sec Tape Units and Separate Controllers
	1600	24 bit I/O Channel (6024-042 & 043)
	2000	Automatic Block Controller (DMA)
Total	$ 296350	

Option 2a

	PURCHASE	EQUIPMENT
	$ 88250	Basic Equipment
	17500	8K Extra Core
	35000	2 - 9T 30 Kc/sec Tape Units and Controller
	23000	7 mb Disc Pack and Controller
	1600	24 bit I/O Channel (6024-042 & 043)
Total	$ 165350	

Option 2b

	PURCHASE	EQUIPMENT
	$ 88250	Basic Equipment
	54500	24K Extra Core and Rack
	35000	2 - 9T 30 Kc/sec Tape Units and Controller
	1600	24 bit I/O Channel (6024-042 & 043)
Total	$ 179350	

* bpw ≡ bits per word.

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APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

Data Craft DC-6024/1 (24 bpw) No Rental Available

Option 3a

	PURCHASE	EQUIPMENT
	$ 88250	Basic Equipment
	17500	8K Extra Core
	23000	7 mb Disc Pack and Controller
	35000	2 - 9T 30 Kc/sec Tape Drivers and Controller
Total	$ 163750	

Option 3b

	PURCHASE	EQUIPMENT
	$ 88250	Basic Equipment
	37000	16K Extra Core
	35000	2 - 9T 30 Kc/sec Tape Units and Controller
Total	$ 160250	

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

DEC PDP - 11 - 45 (16 bpw) No Rental Available

Basic Equipment		PURCHASE	EQUIPMENT
(Needed for All Options)		$ 13000	CPU - with ASR 33
		5000	Fl. Pt. Hardware
		4500	Card Reader
		17500	Line Printer 300 lpm
		1700	Unibus Repeater
	Total	$ 41700	
Option 1			
		$ 1200	DMA
		41700	Basic Equipment
		8000	4 Memory Controllers
		11000	1.2 mb Disc Pack
		92000	64K MOS, 450 nsec
		4000	4 Memory Management
		27000	1- 9T 60K Tape Unit and 1- 9T 240K Tape Unit and Controllers
	Total	$ 184900	
Option 2a			
		$ 41700	Basic Equipment
		12000	16K Core - 850 nsec cycle
		11000	1.2 mb Disc Pack
		17000	2 - 9T 40Kc/sec Magnetic Tape Units and Controller
	Total	$ 81700	
Option 2b			
		$ 41700	Basic Equipment
		23000	32K Core - 850 nsec
		17000	2 - 9T 40 Kc/sec Tapes and Controller
		4000	Memory Management
	Total	$ 85700	
Option 3a			
		$ 41700	Basic Equipment
		12000	16K Core - 850 nsec cycle
		11000	1.2 mb Disc Pack
		17000	2 - 9T 40 Kc/sec Magnetic Tape Units And Controller
	Total	$ 81700	

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

DEC PDP - 11 - 45 (16 bpw) No Rental Available

		PURCHASE	EQUIPMENT
Option 3b			
		$ 41700	Basic Equipment
		17000	24K Core - 850 nsec
		17000	2 - 9T 40 Kc/sec Tapes and Controller
	Total	$ 75700	

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

XDS SIGMA-3 (16 bpw)

Basic Equipment	PURCHASE	RENT*	EQUIPMENT
(Needed for All Options)	$ 22500	$ 563	Line Printer - 225 lpm
	9000	220	Card Reader - 200 cpm
	540	15	Clocks
	5600	140	Console
	3000	75	Extended Arithmetic Unit
	23000	900	2 - 9T 30 Kc/sec Tape Units and Controller
Totals	$ 63640	$ 1913	

Option 3a

	PURCHASE	RENT*	EQUIPMENT
	$ 63640	$ 1913	Basic Equipment
	29000	804	CPU - #8101, with 8K core
	13000	350	8K Extra Core
	35000	950	12.2 m words Disc
Totals	$ 140640	$ 4017	

Option 3b

	PURCHASE	RENT*	EQUIPMENT
	$ 63640	$ 1913	Basic Equipment
	29000	804	CPU #8101, with 8K core
	26000	700	16K Extra Core
Totals	$ 118640	$ 3400	

No Good For Options 1 & 2 - Floating Point Operations Are Too Slow.

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* Monthly rent includes maintenance.

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

XDS SIGMA-5 (32 bpw)

Basic Equipment		PURCHASE	RENT*	EQUIPMENT
(Needed For All Options)		$ 77000	$ 1914	CPU - with 4 IIOP Channels, Memory Protect, Power Fail-safe, Interrupt Control
		10000	250	Floating Point Hardware
		9000	220	Card Reader - 200 cpm
		22500	563	Line Printer - 225 lpm
	Totals	$ 118500	$ 2947	
Option 1				
		$ 118500	$ 2947	Basic Equipment
		140000	5475	48K Memory
		2000	50	DIO
		118000	2805	2 - 9T 120 Kc/sec Tape Units and Separate Controllers
		35000	1200	24 mb Disc Pack
		12000	450	DMA
	Totals	$ 425500	$12927	
Option 2a				
		$ 118500	$ 2947	Basic Equipment
		55000	1825	16K Memory
		35000	1200	24 mb Disc Pack and Controller
		2000	50	DIO
		23000	900	2 - 9T 40 Kc/sec Tape Units and Controller
	Totals	$ 233500	$ 6922	
Option 2b				
		$ 118500	$ 2947	Basic Equipment
		85000	3650	32K Memory
		2000	50	DIO
		23000	900	2 - 9T 40 Kc/sec Tape Units and Controller
	Totals	$ 228500	$ 7547	

* Monthly rental includes maintenance.

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

XDS SIGMA-5 (32 bpw)

	PURCHASE	RENT*	EQUIPMENT
Option 3a			
	$ 118500	$ 2947	Basic Equipment
	42000	1050	8K Memory
	23000	900	2 - 9T 30 Kc/sec Tape Units and Controller
	35000	1200	24 mb Disc Pack (312K bps) with Controller
Totals	$ 218500	$ 6097	
Option 3b			
	$ 118500	$ 2947	Basic Equipment
	55000	1825	16K Memory
	23000	900	2 - 9T 30 Kc/sec Tapes and Controller
Totals	$ 196500	$ 5672	

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* Monthly rent includes maintenance.

APPENDIX C

CANDIDATE COMPUTER CONFIGURATIONS AND COSTS (Cont'd)

IBM – 370 – 135 (32 bpw)

	PURCHASE	RENT*	EQUIPMENT
Basic Equipment (Needed for all Options)	$ 23910	$ 390	Line Printer – 340 lpm
	14590	260	Card Reader – 600 cpm
	5760	180	Console – 3210 Mod. 2
	290000	5670	CPU with FP h/w with 24 Kw Memory and 16 Mupltiplex Channels and 1 Shared Channel
Totals	$ 334260	$ 6500	
Option 1			
	$ 334260	$ 6500	Basic Equipment
	80000	1800	24K Extra Core
	38000	1000	3 Discs (90 mb) and Controller
	74160	1885	2 - 9T Tapes with Controllers; one 320 Kc/sec; the other 50 Kc/sec
Totals	$ 526420	$11185	
Option 2a			
	Not Applicable		24K Minimum Memory
Option 2b			
	$ 334260	$ 6500	Basic Equipment
	34000	800	(24K) 2 - 9T 40 Kc/sec Tape Units with Controller
	$ 368260	$ 7300	
Option 3a			
	Not Applicable		24K Minimum Memory
Option 3b			
	Not Applicable		24K Minimum Memory

* Monthly rent includes maintenance.

VIII. REFERENCES

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Source AFSCR 23-50, 11 May 70